Volume 32
Number 439 *Combinations of rotations and fertilization to maximize crop profits on farms in north-central Iowa (An application of linear programming)*

Article 1

April 1956

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Combinations of Rotations and Fertilization to Maximize Crop Profits On Farms in North-Central Iowa

(An Application of Linear Programming)

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RESEARCH BULLETIN 439 **APRIL, 1956** **AMES, IOWA**

CONTENTS

SUMMARY

1. High level fertilization is a possible practice on many farms in north-central Iowa. With the use of more fertilizer and higher fertilization levels has come the question of what combinations of rotations and fertilizer are optimum. This study is concerned with the selection of the most profitable combination of fertilization and rotations for owner-operated and cash-rented farms on Nicollet-Webster soils where erosion is not considered a major problem. This study examines the effect of different labor levels, amounts of operating capital, fertilizer costs, crop prices, methods of handling hay ground and amounts of land in selecting optimum crop plans for a farm on Nicollet-Webster type soils. The linear programming process is used in selecting plans which maximize crop profits on an owner-operated or cash-rented farm where the time span is long enough to allow realization of the yield effects of different rotations.

2. Situations used as a basis for comparison include: eight rotations each with four fertility treatments, four main levels of operating capital, three levels of labor, 160 and 240 acres of land, and adequate machinery for farming operations. Input-output coefficients are based on 1948-52 costs and prices, yield data as reported by the Department of Agronomy at Iowa State College and average labor requirements for crops. The four main levels of capital consist of $1,500, $3,000, $4,500 and an unlimiting quantity. The labor levels consist of 260 hours of operator labor per month adjusted for inclement weather preventing field work; operator plus 130 hours of family labor for each month of June, July and August; and an unlimiting supply of labor. Plans are determined using various combinations of resources under the conditions described above for a 160-acre and a 240-acre farm.

3. Plans are obtained for parallel groups of resource situations as above but considering the following variations: (a) an increase of 50 percent in fertilizer price; (b) an increase of 36 percent in hay price; (c) operator labor adjusted for the average number of livestock on farms in north-central Iowa; (d) renting of hay ground on 50-50 shares; and (e) maximization of feed production rather than crop profits on 160 acres. These more extreme pricing situations are used since they are the considerations most likely to cause rotation-fertilizer balances to differ from those outlined for average price periods.

4. A rotation of 80 acres of CCOM without fertilization is the most profitable plan where $1,500 capital is used in the basic situations (see paragraph 2 above). A shortage of capital limits the acreage used; however, crops requiring less capital per acre while permitting use of more land would be less profitable than CCOM. As the capital level is increased, rotations using more fertilizer and less meadow enter the optimum plans. At an unlimiting capital and labor level, a corn-soybeans rotation with the highest level of fertilization becomes the most profitable plan. However, CCOM and CSbCOM rotations at the next to the highest level of fertilization and also continuous corn at the highest level of fertilization provide only slightly lower crop profits than corn-soybeans. Thus, farmers have several different rotations from which to choose when they have unlimiting capital and labor resources. Operator labor alone is sufficient to handle all optimum plans for this basic group of situations. Several rotations ranging from continuous row crops fertilized at high levels to CCOM may give similar plans where sufficient capital is available. However, use of a greater amount of meadow in the rotation lowers profits by larger amounts.

5. An increase of 50 percent in fertilizer costs to reflect the situation similar to the highest fertilizer/crop price ratio of recent years has no effect on the rotation when only $1,500 capital is available. At higher capital levels, less fertilizer and a greater quantity of meadow is included in the optimum plans when compared to similar resource situations without the fertilizer price increase. When capital is not limitational, a corn-soybeans rotation at the highest fertility level is slightly more profitable than CCOM and CSbCOM with next to the highest levels of fertilization.

6. An increase in hay price of 36 percent relative to the 1948-52 average price results in a decrease in fertilizer use and provides plans containing relatively large amounts of forage. The rotation contains 50 percent meadow when the operator is limited to his own labor supply and has only $1,500 or $3,000 in capital. Optimum plans include only 25 percent meadow (i.e., CCOM at next to highest level of fertilization) with operating capital of $4,500 and above and labor supply restricted to that provided by the operator.

7. Adjustment of operator labor for both inclement weather and labor requirements for a typical livestock organization on a 160-acre farm results in a shortage of operator labor in May and July for some plans. With only operator labor available, CCOM still enters the plan with $1,500 capital; at $3,000 and $4,500 levels, the shortage of operator labor for May and July results in the use of more fertilizer and a lower percentage of meadow than for plans where there is no labor shortage.

8. With a hay value equal to the return from renting out hay ground on 50-50 shares, the optimum plans show a shift toward more row crops and more fertilizer in situations where both land and capital are limitational resources. Less meadow occurs than in other plans using similar resources, as the gross price of hay is cut in half by the rental practice while costs are reduced by only a small amount. A rotation of corn-soybeans with the third level of fertilization occurs with unlimiting capital and labor resources.

9. Increasing the size of the farm from 160 to 240 acres results in similar plans for both sizes of farms for situations using $1,500 capital and the operator's labor. With $3,000 capital, plans for a 240-acre farm contain less fertilizer and more meadow in the rotation because of the scarcity of operating capital. For unlimiting capital and labor situations, plans for the 240-acre and 160-acre farms include identical rotations. Nearly all

plans for situations with $4,500 capital and only operator labor on a 240-acre farm are affected by a shortage of labor either in May or July or both. In general, when there is a shortage of available labor, the optimum plan includes use of greater quantities of fertilizer and less meadow than plans where labor supply is in excess of requirements.

10. Results for a 240-acre farm, as on a 160-acre farm, indicate that recommendations or decisions on the best rotations and fertilization plans differ depending on the operator's capital and labor supply, prices of crops, input quantities and meadow-sharing arrangement.

11. It appears that if one "general purpose" rotation were recommended for Nicollet-Webster soils, it should be CCOM with an appropriate amount of fertilizer. This rotation, more than any other, comes nearest to profit maximization over the greatest number of the situations studied. Where it is not the most profitable rotation, it causes only slight sacrifices in crop profits, as compared to other rotations with a greater proportion of meadow. When the possibilities of converting feed into livestock products are considered, CCOM may return more profit to the farm as a whole than a rotation such as corn and soybeans (or these crops with a small proportion of oats and hay) which results in maximum profits to the cropping sector of the farm business. The optimum rotation, however, is a function of the capital, labor and land available on the individual farm, rather than of land alone.

Combinations of Rotations and Fertilization To Maximize Crop Profits on Farms in North-Central Iowa[1]

(An Application of Linear Programming)

by Earl O. Heady, Robert McAlexander and W. D. Shrader

One problem of farmers is to reorganize the use of their resources as new farming techniques are developed. While not a new technique itself, heavy fertilization of grain crops has not been widespread in Iowa. Recent agronomic research and farmer experience indicate, however, that heavy fertilization rates can be profitable under existing price ratios. Fertilization is a relatively simple practice but it can have complex effects on profitable farm organization.

One of the major impacts of heavy fertilization is on the rotation system. Grasses and legumes grown in rotation can serve in a complementary capacity to grains.[2] As complementary crops, grasses and legumes increase profits to the extent that they (1) provide nitrogen to subsequent grain crops, (2) provide organic matter and improve soil tilth, (3) help control insects and diseases and (4) control erosion. Heavy fertilization substitutes for legumes of the rotation in providing nitrogen for subsequent grain crops. It also may substitute for forages in furnishing organic matter. An acre of heavily fertilized corn, for example, can furnish an equal or a greater weight of plant residues than an acre of clover or alfalfa under particular soil and climatic situations such as in north-central Iowa. Under these conditions, the questions arise: What rotation should be used when corn can be fertilized at heavy rates? Are the profit differences small or great from different crop rotations and fertilization rates? Does the optimum combination of rotations and fertilization rates differ between farms of different size which have varying amounts of operating funds and labor?

OBJECTIVES

The objectives of this study are to provide answers to the questions posed above. The analysis which follows attempts to determine the most profitable combination of fertilization and rotations when the farmer has different amounts of labor and capital on 160-acre and 240-acre farms. This procedure is followed since quite different recommendations may be appropriate for farmers in different resource situations. A farmer with ample capital may be able to get the largest return per acre of land by growing a rotation with a maximum amount of row crops and heavy fertilization rates. However, if his labor supply is limited, the optimum rotation may be one with less corn, fertilized at heavier rates, and more oats and hay to use labor in months when it is not required by corn. Or, where capital is more limited than labor, the operator might best use his scarce funds for a sufficient amount of hay to provide its complementary effect for grain and operate a maximum number of acres with his limited capital.

Total farm costs can sometimes be lessened by growing enough hay to complete the complementary role and letting the hay go unharvested (i.e., plow it under as green manure). If total corn production is increased on the remaining acres, costs of corn output are reduced because the costs of growing an acre of hay are less than the costs of growing and harvesting an acre of corn.[3] Very limited funds can be used to operate more acres, devoted partly to complementary hay in the rotation with unfertilized corn. Returns then will be greater than using the same limited funds for fewer acres of heavily fertilized corn if the return per $1 of capital is greater from farming added land than from fertilizing fewer acres. These possibilities, and others, arise when farmers have different amounts of capital, labor and land. Hence, the linear programming technique is used in this study to determine optimum plans for numerous resource situations.

Application of Principles

The analysis of this study is based on yield predictions and estimates outlined later. These yield estimates are subject to limitations which also are explained at a later point in this study. Yields for various rotations and fertilization practices may need to be re-examined later when additional experimental data are available. However, a central objective of this study is to apply certain fundamental economic principles in determining and illustrating selection of optimum rotation-fertilization combinations to fit the different circumstances on farms with varying resource and price situations. These principles have universal application even when yield coefficients change under new techniques and new experimental determinations.

Linear Programming Application

With the linear programming technique used in this study, many thousands of alternative uses of resources and combinations of crops and practices can be considered.[4] Given the quantities of resources included in the

[1]Project 1085, Iowa Agricultural Experiment Station.

[2]For a detailed analysis of grass and legume crops in complementary and competitive capacities, see: Heady, Earl O. and Jensen, Harald R. The economics of crop rotations and land use. Iowa Agr. Exp. Sta. Res. Bul. 383. 1951.

[3]See Heady and Jensen, op. cit.

[4]For more details on the linear programming technique, see: Bowlen, Bernard and Heady, Earl O. Optimum combinations of competitive crops at particular locations. Iowa Agr. Exp. Sta. Res. Bul. 426. 1955.

analysis, the prices and the input-output coefficients used, the technique considers all possible combinations and indicates the most profitable one. For example, the farmer who has $5,000 which can be used for corn or soybeans already has 5,000 ways in which he can allocate dollars between the two crops. If he has 200 hours of labor available in July, he has 200 x 5,000 or 1 million different ways in which to combine dollars and labor resources for the two crops. Now, if he has 150 hours of labor which can be used in another month, 160 acres of land and 20 different crops or cropping practices, the total possible number of combinations becomes even greater. The linear programming method allows consideration of all of these many possibilities. Also it allows consideration of the limitations imposed by each scarce resource. It considers not only that land may be limited to 160 or 240 acres but also that labor in any particular month, capital or machinery may be limited and important in specifying the optimum rotation and fertilization plan.

In the following analysis, each different rotation and level of fertilization is considered as a different crop possibility (activity). A rotation of CCOM without fertilization is one rotation possibility. The same rotation with a small amount of fertilizer is a separate possibility; still other fertilization treatments for the same rotation are considered as distinct crop opportunities.

The criterion used in this study for selecting rotations and fertilization levels is the greatest profit from crops. Most farmers have the opportunity of producing the most profitable combination of crops, then, of adjusting livestock to the crop program. Grain or other feed can be purchased or sold to allow the most profitable livestock program to be fitted with the most profitable crop program. Hence, the findings of this study refer to situations where the farm is operated on either (1) a cash-crop basis or (2) a system where crops and livestock are considered as distinct lines of the business with purchase and sale of feeds to allow the most profitable selection of each line. Results may be somewhat different, however, where crops and livestock are considered together and are made interdependent. A subsequent study will be made to determine most profitable plans when rotations, fertilization treatments and livestock are considered as interdependent variables.

AREA AND SCOPE OF STUDY

The findings of this study relate to Nicollet-Webster soils in north-central Iowa where erosion is not a major problem. High fertilization rates may be used to substitute partially for legumes in rotations for land which is level. However, the extent to which these changes can be made depends on the particular soil situation and the amount of mechanical practices used to arrest erosion. This study does not relate to extremely long-run considerations of soil structure. Agronomic research does show that a sufficiently heavy fertilization of corn can result in as much or more organic matter added to the upper strata of the soil as when meadow crops are grown. From this standpoint, the upper structure of the soil may be well maintained under heavily fertilized corn. Organic matter from corn does not, however, substitute for the action of legume roots at lower soil strata.

Eight different rotations were considered in this study: namely, continuous corn (C), continuous oats (O), corn - oats - sweetclover (CO_{scl}), corn - soybeans (CSb), corn-corn-oats-meadow (CCOM), corn-oats-meadow (COM), corn - oats - meadow - meadow (COMM) and corn - soybeans - corn - oats - meadow (CSbCOM). Not all of these rotations are commonly used in the area. However, they were included, along with different fertilizer treatments, to determine which are profitable cropping programs under the several resource and price conditions outlined later. The four different fertilization treatments considered for each of the eight rotations are shown in table 1.[5]

No fertilizer is included for soybeans; fertilizer for meadow is applied on oats. Since each level of fertilization is combined with each rotation, there are 32 different combinations of rotations and fertilizer levels (i.e., 32 activities) for consideration in the farm plans.

SITUATIONS CONSIDERED IN STUDY

This study includes 66 different resource-price situations under which the most profitable plans have been determined on 160-acre and 240-acre farms. Six additional situations are considered where maximum feed production is the goal. A new situation exists for every change in prices, costs, method of farming, or quantity of available land, labor or capital. For convenience in presentation, situations are classified into groups as shown in table 2.

Situation Groups

Group 1 includes situations with (a) average 1948-52 prices and costs, (b) capital resource levels ranging from $1,500 to a non-limitational capital level, (c) labor levels ranging from operator labor adjusted for inclement weather preventing field work to an unlimiting supply of labor and (d) land resource of 160 and 240 acres. Situations S_{1a} to S_{8a} and S_{1b} to S_{8b} are included in this group.

Group 2 situations include the same prices, costs and resources as Group 1 except (a) fertilizer costs have been increased by 50 percent over those of 1948-

[5]Use of only four levels of fertilizer does not mean that these are the best for the area. These are rates that have been used in experimental work. There are an infinite number of combinations that could have been included in the study, but this would have increased the computations of the study beyond reasonable proportions. These four levels were selected for comparing applications of nonuse of fertilizer to that of quite a high rate of application, with two intermediate levels.

TABLE 1. APPLICATION RATES OF AVAILABLE NITROGEN (N), PHOSPHORUS (P_2O_5) AND POTASSIUM (K_2O) PER ACRE FOR VARIOUS CROPS IN ROTATIONS.*

Fertilizer treatments	Pounds available nutrients applied to corn			Pounds available nutrients applied to oats in rotations			Pounds available nutrients applied to continuous oats		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
0	0	0	0	0	0	0	0	0	0
1	30	40	30	10	20	10	10	20	10
2	60	40	30	10	20	10	30	20	10
3	120	60	40	0	40	20	60	40	30

*Data obtained from the Department of Agronomy, Iowa State College. No fertilizer was applied to soybeans; fertilizer for meadow was applied to oats.

52 and (b) the $4,600 and $4,700 capital levels were not included in this group. The change in fertilizer

TABLE 2. RESOURCE COMBINATIONS FOR VARIOUS GROUPS OF SITUATIONS.

Group	Situation number	Capital level (dollars)	Labor level	Size of farm (acres)
(1)	1948-52 prices and costs; operator labor adjusted for inclement weather.			
	S_{1a}	1,500	operator	160
	S_{2a}	3,000	operator	160
	S_{3a}	4,500	operator	160
	S_{4a}	3,000	operator & family	160
	S_{5a}	4,500	operator & family	160
	S_{6a}	4,600	unlimiting	160
	S_{7a}	4,700	unlimiting	160
	S_{8a}	unlimiting	unlimiting	160
	S_{1b}	1,500	operator	240
	S_{2b}	3,000	operator	240
	S_{3b}	4,500	operator	240
	S_{4b}	3,000	operator & family	240
	S_{5b}	4,500	operator & family	240
	S_{6b}	6,000	operator	240
	S_{7b}	6,000	operator & family	240
	S_{8b}	unlimiting	unlimiting	240
(2)	1948-52 prices and costs; operator labor adjusted for inclement weather; fertilizer prices increased by 50 percent over 1948-52 prices corresponding to highest prices relative to corn in the last 15 years (i.e., 1941-42).			
	S_{9a}	1,500	operator	160
	S_{10a}	3,000	operator	160
	S_{11a}	4,500	operator	160
	S_{12a}	3,000	operator & family	160
	S_{13a}	4,500	operator & family	160
	S_{14a}	unlimiting	unlimiting	160
	S_{9b}	1,500	operator	240
	S_{10b}	3,000	operator	240
	S_{11b}	4,500	operator	240
	S_{12b}	3,000	operator & family	240
	S_{13b}	4,500	operator & family	240
	S_{14b}	6,000	operator	240
	S_{15b}	6,000	operator & family	240
	S_{16b}	unlimiting	unlimiting	240
(3)	1948-52 prices and costs; operator labor adjusted for inclement weather; hay price increased by 36 percent over 1948-52 prices corresponding to its highest price relative to corn in the last 35 years (i.e., 1920-24).			
	S_{15a}	1,500	operator	160
	S_{16a}	3,000	operator	160
	S_{17a}	4,500	operator	160
	S_{18a}	3,000	operator & family	160
	S_{19a}	4,500	operator & family	160
	S_{20a}	unlimiting	unlimiting	160
	S_{17b}	1,500	operator	240
	S_{18b}	3,000	operator	240
	S_{19b}	4,500	operator	240
	S_{20b}	3,000	operator & family	240
	S_{21b}	4,500	operator & family	240
	S_{22b}	unlimiting	unlimiting	240
(4)	1948-52 prices and costs; operator labor adjusted for average number of livestock on 160-acre and 240-acre farms in north-central Iowa.			
	S_{21a}	1,500	operator	160
	S_{22a}	3,000	operator	160
	S_{23a}	4,500	operator	160
	S_{24a}	3,000	operator & family	160
	S_{25a}	4,500	operator & family	160
	S_{26a}	unlimiting	unlimiting	160
	S_{23b}	1,500	operator	240
	S_{24b}	3,000	operator	240
	S_{25b}	4,500	operator	240
	S_{26b}	3,000	operator & family	240
	S_{27b}	4,500	operator & family	240
	S_{28b}	unlimiting	unlimiting	240
(5)	1948-52 prices and costs; operator labor adjusted for inclement weather; hay ground rented out on 50-50 share basis.			
	S_{27a}	1,500	operator	160
	S_{28a}	3,000	operator	160
	S_{29a}	4,500	operator	160
	S_{30a}	3,000	operator & family	160
	S_{31a}	4,500	operator & family	160
	S_{32a}	unlimiting	unlimiting	160
	S_{29b}	1,500	operator	240
	S_{30b}	3,000	operator	240
	S_{31b}	4,500	operator	240
	S_{32b}	3,000	operator & family	240
	S_{33b}	4,500	operator & family	240
	S_{34b}	unlimiting	unlimiting	240
(6)	1948-52 prices and costs; operator labor adjusted for inclement weather; production of feed units maximized.			
	S_{33a}	1,500	operator	160
	S_{34a}	3,000	operator	160
	S_{35a}	4,500	operator	160
	S_{36a}	3,000	operator & family	160
	S_{37a}	4,500	operator & family	160
	S_{38a}	unlimiting	unlimiting	160

price was made to determine the effect which various fertilizer price ratios have on the optimum rotation and fertilization level. The 50-percent increase is taken, not as a prediction of future prices, but as the most unfavorable price ratio of fertilizer to corn which existed in the past 15 years. This most unfavorable period was in 1941-42. Situations S_{9a} to S_{14a} and S_{9b} to S_{16b} are included in this group.

Group 3 situations include similar prices, costs and resources as Group 1 except (a) fewer capital levels have been considered, (b) the price of hay has been increased by approximately 36 percent. The change in hay price was made to determine the effect of more favorable forage prices on the optimum program. This price for forage corresponds to the most favorable price period for forage in the past 35 years; namely from 1920 to 1924. Situations S_{15a} to S_{20a} and S_{17b} to S_{22b} are included in Group 3.

Group 4 includes situations which are similar to those under Group 1 except that (a) there are fewer capital levels included and (b) operator labor supply for crops is lower. Group 4 has operator labor adjusted for both inclement weather and the average number of livestock on 160-acre and 240-acre farms in north-central Iowa. Situations under Group 4 are S_{21a} through S_{26a} and S_{23b} through S_{28b}.

Group 5 situations are similar to those of Group 1 except that (a) fewer capital levels are used and (b) hay ground is rented out on a 50-50 share basis. This method of handling hay ground was used to determine whether a particular leasing arrangement would affect the optimum rotation-fertilization program. Share renting the hay ground is simply a different method of pricing hay. The situations in this group differ from those under Group 3 in this manner: The price for hay is more favorable than average under Group 3, while hay returns are made less favorable under Group 5 by receiving only half the hay. Situations S_{27a} to S_{32a} and S_{29b} to S_{34b} are included in Group 5.

Group 6 includes the same costs and labor levels as Group 1, but differs in that (a) fewer capital levels are included, (b) only 160 acres of land are considered and (c) feed units rather than crop profits are maximized. Situations under Group 6 are S_{33a} to S_{38a}, inclusive.

PRICES AND RESOURCE QUANTITIES

Prices

Average 1948-52 prices are used for all situations except for Group 3. In Group 3 situations, the price of hay is increased to the 1920-24 relative level; its highest price relative to corn during the 35 years. The prices used for the different crops are shown in table 3.

TABLE 3. CROP PRICES USED FOR VARIOUS GROUPS OF PRICE-RESOURCE SITUATIONS.*

Crop	Average 1948-52 prices used in groups 1, 2, 4 & 5 (dollars)	1948-52 prices with hay increased 36% for Group 3. (dollars)
Corn/bu.	1.45	1.45
Oats/bu.	0.764	0.764
Soybeans/bu.	2.54	2.54
Hay/ton	21.48	29.23

*Source: Iowa Crop and Livestock Reporting Service.

Capital Levels

Four different capital levels are used for each group of situations[6] (table 2). In addition, capital levels of $4,600 and $4,700 are used for two situations on a 160-acre farm, and a level of $6,000 is used in three situations on a 240-acre farm.

Capital refers to operating capital; that is, funds for annual expenses for such items as tractor costs, building costs, repairs and depreciation on machinery, seed, fertilizer, hired labor and harvesting costs. It is assumed that the farmer has his own equipment for operating the farm. New machinery at 1948-52 prices would cost approximately $10,172. If machinery is partially depreciated, or bought secondhand, the average investment in machinery is estimated to be about $5,594.[7] Hence, where the capital level is shown as $3,000 in table 2, this actually represents a capital resource of about $8,594 if we include an average investment of $5,594 for machinery investment. Land, of course, is a further resource which must be made available by ownership or renting.

Labor Levels

Some farmers use only their own labor; some have their own labor plus that of family members. Other farmers hire whatever labor is needed. Each labor situation provides a basis for a different plan. Consequently, situations are determined using several different labor levels as listed below.

1. *Operator labor adjusted for weather not permitting field work.* Total operator labor is based on 26, 10-hour working days per month. Since unfavorable weather prevents use of all 260 hours for field work, adjustments were made for inclement weather. The hours available for field work by the operator for each month are shown in column 5 of table 4. These quantities were used in all situations where operator labor is entered as a limiting resource with the exception of situations S_{21a} through S_{25a} and S_{23b} through S_{27b} in Group 4 (see paragraph 2 below for description of labor for these situations).

2. *Operator labor adjusted for (a) weather prohibiting field work and (b) labor requirements of the estimated average number of livestock on 160-acre and 240-acre farms in north-central Iowa.*[8] Situations of Group 4 (i.e., S_{21a} - S_{25a} and S_{23b} - S_{27b}) are included under this level of operator labor. In these situations, estimated labor requirements have been deducted for an average amount of livestock on 160-acre and 240-acre farms in the area. Data in tables 4 and 5 show the procedure used for computing quantities of available operator labor for various months. For example,

[6]Unlimiting capital resource means that operating capital is available in sufficient quantity so that it does not limit production in the most profitable plan. That is, other resources become limitational before capital is used up.

[7]Average investment is defined as ½ (purchase price + 10 percent trade-in). See: Hussain, S. M. Cost relationships in farm machinery use. Unpublished M. S. thesis. Iowa State College Library, Ames, Iowa. 1949. p. 59; and Kansas Engineering Experiment Station bulletins No. 45 (1945) and 74 (1954).

[8]The number of livestock on 160-acre and 240-acre farms in north-central Iowa was based on a survey taken in 1950 and 1951.

TABLE 4. METHOD OF COMPUTING QUANTITY OF OPERATOR LABOR AVAILABLE FOR CROP PRODUCTION FOR EACH MONTH FOR A 160-ACRE FARM.

Item (1)	Total working hours per month* (2)	Estimated livestock labor requirements on 160-acre farm† (3)	Labor available for uses other than livestock (column 2-column 3) (4)	Hours of favorable weather for field work (5)	Hours available for crop production, adjusted for livestock labor requirements and weather restrictions (6)	Hours available for crop production when 130 hrs. family labor added for June July and Aug. (7)
March	260.0	180.1	79.9	28.5	28.5	28.5
April	260.0	151.0	109.0	187.2	109.0	109.0
May	260.0	161.6	98.4	203.3	98.4	98.4
June	260.0	131.2	128.8	203.9	128.8	258.8
July	260.0	120.5	139.5	241.3	139.5	269.5
Aug.	260.0	120.4	139.6	227.1	139.6	269.6
Sept.	260.0	120.5	139.5	234.6	139.5	139.5
Oct.	260.0	144.0	116.0	235.9	116.0	116.0
Nov.	260.0	150.8	109.2	168.0	109.2	109.2

*Total labor available per month is based on 26 working days at 10 hours per day.

†Labor requirements and monthly distribution of labor based on a report by United States Department of Agriculture, Iowa Agricultural Experiment Station and Iowa Agricultural Extension Service cooperating. Iowa maximum agricultural capacity. [Unpublished report.] Iowa State College, Ames, Iowa. 1952.

TABLE 5. METHOD OF COMPUTING QUANTITY OF OPERATOR LABOR AVAILABLE FOR CROP PRODUCTION FOR EACH MONTH FOR A 240-ACRE FARM.

Item (1)	Total working hours per month* (2)	Estimated livestock labor requirements on 240-acre farm† (3)	Labor available for uses other than livestock (column 2-column 3) (4)	Hours of favorable weather for field work (5)	Hours available for crop production, adjusted for livestock labor requirements and weather restrictions (6)	Hours available for crop production when 130 hrs. family labor added for June, July and Aug. (7)
March	260.0	158.1	101.9	28.5	28.5	28.5
April	260.0	141.6	118.4	187.2	118.4	118.4
May	260.0	152.4	107.6	203.3	107.6	107.6
June	260.0	121.1	138.9	203.9	138.9	268.9
July	260.0	109.1	150.9	241.2	150.9	280.9
Aug.	260.0	108.0	152.0	227.1	152.0	282.0
Sept.	260.0	106.3	153.7	234.6	153.7	153.7
Oct.	260.0	118.4	141.6	235.9	141.6	141.6
Nov.	260.0	127.5	132.5	168.0	132.5	132.5

*Total labor available per month is based on 26 working days at 10 hours per day.

†Labor requirements and monthly distribution of labor based on a report by United States Department of Agriculture, Iowa Agricultural Experiment Station and Iowa Agricultural Extension Service cooperating. Iowa maximum agricultural capacity. [Unpublished report.] Iowa State College, Ames, Iowa. 1952.

table 4, column 2 shows the total number of hours available each month. By subtracting the estimated labor requirements for a typical livestock organization on 160 acres (column 3) from the total available operator labor (column 2), the labor available for other uses is obtained (column 4). Column 6 shows the available monthly labor quantities for crop production, adjusted for livestock labor requirements and weather restrictions.

3. *Operator labor plus 130 hours of family labor in June, July and August.* Solutions using this labor supply have been computed only for situations with capital levels of $3,000, $4,500 and $6,000. The purpose of this increased labor supply is to determine its effect on the optimum rotation program.

4. *Unlimiting labor.* Situations are considered in each group where labor does not limit the plan below the profit level attainable from the most efficient use of the supply of land and capital. In other words, the farmer would hire labor whenever it was needed.

Land

The land resource used in this study refers to 160-acre and 240-acre farms of Nicollet loam or Webster silt clay loam. These soil types are typical of much of the cash grain area of north-central Iowa. Although 160-acre and 240-acre farms are the most common sizes in the area, it is estimated that 148 and 224 acres, respectively, would be available for crop production after adjustments for farmstead, roads, fences, etc. Solutions have been computed for both farm sizes in all groups of situations except those for Group 6, where only a 160-acre farm is used in application of linear programming to determine the plan which maximizes feed production.

COEFFICIENTS OF PRODUCTION

Coefficients of production used in the computations of the various plans are based on feed units of rotation. These feed units were computed on a TDN basis. One bushel of No. 2 yellow corn equals 1 feed unit; 1 bushel of oats equals 0.50001 feed units; 1 bushel of soybeans equals 1.1718 feed units; 1 ton of hay equals 21.8922 feed units.[9] Feed units were selected, not because they have any meaning *per se*, but for the purpose of obtaining a common denominator for obtaining unit prices, costs and labor and land requirements for the joint output of the various activities. Input coefficients for the different activities (i.e., quantities of capital, labor and land required per feed unit of output) were determined as follows: Requirements for capital and labor were obtained for each crop and each fertility level under each rotation. From this information, capital and labor requirements for each "rotational acre" for the various rotations and fertilizer treatments were determined. Next, requirements per feed unit were computed by dividing the capital and labor requirements of each activity by the corresponding number of feed units produced on an acre.

[9]Feed unit computations based on data from: Morrison, F. B. Feeds and feeding. 21st edition. Morrison Publishing Co., Ithaca, New York. 1948. Appendix, Table I.

Capital Coefficients

Capital requirements per feed unit for the various crop rotations and fertility levels are shown in table 6. Capital coefficients of situations for groups 1, 3, 4 and 6 are the same for corresponding rotations and fertility treatments; Group 2 situations have higher capital requirements for rotations containing fertilizer than other groups because of the increase in the price of fertilizer. Situations of Group 5 have lower capital requirements for all situations containing meadow since harvest costs are not included.

Labor Coefficients

Monthly labor requirements are on an acre basis and are shown in tables 7 and 8. Table 7 refers to the monthly distribution of labor requirements for situations of groups 1, 2, 3, 4 and 6. Data in table 8 provide the per-acre labor requirements for situations S_{27a} through S_{32a} and S_{29b} through S_{34b} of Group 5. The first step in obtaining labor coefficients was to obtain estimates of labor requirements for individual crops on a per-acre basis. These quantities include only the labor requirements of the operator. Hired labor used for haying, harvesting of oats, corn and soybeans is entered as cash expense.

Land Coefficients

Yield estimates relate to Nicollet loam or Webster silt

TABLE 6. CAPITAL COEFFICIENTS PER FEED UNIT OF CROP ROTATIONS WITH FOUR DIFFERENT FERTILITY TREATMENTS FOR VARIOUS GROUPS OF SITUATIONS.*

Fertility treatment	Capital requirement or annual costs per feed unit of rotation for various fertility treatments (dollars)							
	C	O	CO_{scl}	CSb	CCOM	COM	COMM	CSbCOM
Groups 1, 3, 4, 6:								
0	0.51571	0.85732	0.52533	0.53684	0.37115	0.38411	0.35996	0.40459
1	0.57940	0.86198	0.58011	0.54278	0.39738	0.38454	0.35073	0.41271
2	0.52462	0.81518	0.56985	0.50940	0.38989	0.38685	0.35997	0.40083
3	0.57538	1.01416	0.62327	0.51057	0.46639	0.45276	0.42391	0.46123
Group 2:								
0	0.51571	0.85732	0.52533	0.53684	0.37115	0.38411	0.35996	0.40459
1	0.67900	0.96281	0.66011	0.60084	0.44431	0.42218	0.37900	0.45438
2	0.63323	0.95158	0.66297	0.57929	0.44619	0.43298	0.39581	0.45095
3	0.73238	1.27088	0.76145	0.61093	0.56210	0.53060	0.48640	0.54505
Group 5:								
0	0.51571	0.85732	0.52533	0.53684	0.34500	0.34757	0.30762	0.38133
1	0.57940	0.86198	0.58011	0.54278	0.37407	0.35239	0.30420	0.39205
2	0.52462	0.81518	0.56985	0.50940	0.36843	0.35548	0.31292	0.38174
3	0.57538	1.01416	0.62327	0.51057	0.44516	0.42107	0.37643	0.44251

*Capital coefficients were obtained by dividing capital cost per acre by the number of feed units produced on each acre. Fixed costs are not included in these figures

TABLE 7. TOTAL AND MONTHLY DISTRIBUTION OF LABOR REQUIREMENTS FOR SITUATIONS OF GROUPS 1, 2, 3, 4 AND 6 FOR EIGHT ROTATIONS AND FOUR FERTILITY TREATMENTS.*

Rotation (1)	Fertilizer treatment† (2)	Total hours required per acre (3)	Hours of labor required per acre of activity by months									
			March (4)	April (5)	May (6)	June (7)	July (8)	Aug. (9)	Sept. (10)	Oct. (11)	Nov. (12)	Dec. (13)
Corn	0	7.00	0	0.82	1.54	0.92	0.75	0	0.14	1.04	1.43	0.36
	1, 2, 3	7.25	0	1.07	1.54	0.92	0.75	0	0.14	1.04	1.43	0.36
Oats	0	5.00	0.36	0.90	0	0	1.87	1.87	0	0	0	0
	1, 2, 3	5.30	0.66	0.90	0	0	1.87	1.87	0	0	0	0
CO_{scl}	0	6.00	0.18	0.86	0.77	0.46	1.31	0.94	0.07	0.52	0.71	0.18
	1, 2, 3	6.28	0.33	0.99	0.77	0.46	1.31	0.94	0.07	0.52	0.71	0.18
CSb	0	6.50	0	0.71	1.50	0.89	0.71	0	0.16	1.64	0.71	0.18
	1, 2, 3	6.62	0	0.83	1.50	0.89	0.71	0	0.16	1.64	0.71	0.18
CCOM	0	4.90	0.09	0.64	0.77	0.80	1.19	0.52	0.18	0.26	0.36	0.09
	1	5.34	0.16	0.76	0.77	0.91	1.29	0.53	0.21	0.26	0.36	0.09
	2, 3	5.41	0.16	0.76	0.77	0.94	1.32	0.53	0.22	0.26	0.36	0.09
COM	0	4.87	0.12	0.33	0.51	0.76	1.33	0.69	0.19	0.34	0.48	0.12
	1	4.65	0.22	0.66	0.51	0.90	1.47	0.71	0.24	0.34	0.48	0.12
	2, 3	5.74	0.22	0.66	0.51	0.94	1.51	0.71	0.25	0.34	0.48	0.12
COMM	0	4.58	0.09	0.43	0.38	0.87	1.30	0.56	0.24	0.26	0.36	0.09
	1	5.18	0.16	0.49	0.38	1.07	1.49	0.58	0.30	0.26	0.36	0.09
	2	5.34	0.16	0.49	0.38	1.13	1.55	0.59	0.32	0.26	0.36	0.09
	3	5.18	0.16	0.49	0.38	1.07	1.49	0.58	0.30	0.26	0.36	0.09
CSbCOM	0	5.68	0.07	0.63	0.91	0.82	1.08	0.41	0.18	0.86	0.57	0.15
	1	6.04	0.13	0.73	0.91	0.90	1.17	0.42	0.20	0.86	0.57	0.15
	2, 3	6.10	0.13	0.73	0.91	0.92	1.19	0.43	0.21	0.86	0.57	0.15

*Monthly labor distribution on basis of a report by United States Department of Agriculture, Iowa Agricultural Experiment Station and Iowa Agricultural Extension Service cooperating. Iowa maximum agricultural capacity. [Unpublished report.] Iowa State College, Ames, Iowa. 1952.

†See table 1 for explanation of fertility treatments. Labor for fertilizer treatment is required primarily in March and/or April. The amounts of labor required for fertilization treatment do not vary between fertilization levels 1, 2 and 3. However, increased quantities of hay at high fertilization levels on the meadow rotations increase labor requirements accordingly.

TABLE 8. TOTAL AND MONTHLY DISTRIBUTION OF LABOR REQUIREMENTS FOR GROUP 5 SITUATIONS WITH HAY GROUND RENTED ON 50-50 SHARES.*

Rotation (1)	Fertilizer treatment† (2)	Total hours required per acre (3)	Hours of labor required per acre of activity by months									
			March (4)	April (5)	May (6)	June (7)	July (8)	Aug. (9)	Sept. (10)	Oct. (11)	Nov. (12)	Dec. (13)
CCOM	0	3.86	0.09	0.64	0.77	0.46	0.65	0.47	0.07	0.26	0.36	0.09
	1, 2, 3	4.06	0.16	0.76	0.77	0.46	0.65	0.47	0.07	0.26	0.36	0.09
COM	0	3.76	0.12	0.33	0.51	0.31	0.88	0.62	0.05	0.34	0.48	0.12
	1, 2, 3	4.19	0.22	0.66	0.51	0.31	0.88	0.62	0.05	0.34	0.48	0.12
COMM	0	3.00	0.09	0.43	0.38	0.23	0.65	0.47	0.04	0.26	0.36	0.09
	1, 2, 3	3.13	0.16	0.49	0.38	0.23	0.65	0.47	0.04	0.26	0.36	0.09
CSbCOM	0	4.86	0.07	0.63	0.91	0.54	0.66	0.38	0.09	0.86	0.57	0.15
	1, 2, 3	5.02	0.13	0.73	0.91	0.54	0.66	0.38	0.09	0.86	0.57	0.15

*Monthly labor distribution on basis of report by United States Department of Agriculture, Iowa Agricultural Experiment Station and Iowa Agricultural Extension Service cooperating. Iowa maximum agricultural capacity. [Unpublished report] Iowa State College, Ames, Iowa. 1952.

†See table 1 for explanation of fertility treatments. Labor for fertilizer treatment is required only in March and April. Equal per-month labor requirements are assumed for fertilization levels 1, 2 and 3.

clay loam with adequate drainage and where erosion is not a major problem. They assume a previous land use system of a corn-corn-oats-meadow rotation and moderate manure applications over a period of 20 years and are based on average weather conditions. Also included as a basis for yield estimates are the following conditions: no field loss of grain (or, alternatively, that field loss would be recovered through livestock); a corn stand of 14,000 stalks per acre; use of crop varieties best adapted to the area; seeding mixture for meadow of 4 pounds of red clover, 6 pounds of alfalfa and 4 pounds of timothy. In other words, the estimates assume a high level of crop and soil management. Lower levels of management would give smaller yields. Yield estimates for the lower fertility levels are estimated to be subject to less error than the two highest levels of fertility treatment. The latter are based on less complete information. Estimated yields in terms of feed units per acre of the various activities are shown in table 9. To facilitate computations, yields of all rotations and fertility treatments were converted to land coefficients. Land coefficients represent the quantity of land required to produce 1 feed unit of each of the rotations and fertility treatments.

PRESENTATION AND INTERPRETATION OF RESULTS

The optimum plans for the various resource situations which are presented in subsequent sections have been

TABLE 9. YIELD IN FEED UNITS PER ACRE* FOR ROTATIONS WITH FOUR FERTILITY TREATMENTS.

Fertility treatment†	Yield in feed units per acre for rotations with four fertility treatments							
	C	O	CO_{scl}	CSb	CCOM	COM	COMM	CSbCOM
0	35.0	15.0	33.8	33.0	50.1	47.6	48.4	45.2
1	50.0	20.0	43.8	42.9	63.9	61.9	61.9	57.6
2	65.0	25.0	48.8	50.6	71.8	65.7	63.3	64.4
3	80.0	27.5	55.0	62.6	72.5	65.0	60.6	66.2

*Feed units were computed on a TDN basis. One bushel of No. 2 yellow corn equals 1 feed unit; 1 bushel of oats equals 0.50001 feed units; 1 bushel of soybeans equals 1.1718 feed units; 1 ton of hay equals 21.8922 feed units.

†See table 1 for explanation of fertility treatments.

computed by the "simplex" method of linear programming.[10] The criterion used for selection is profit maximization from crops.[11] While other plans might give higher crop profit levels under different resource and price situations, the programs shown are those which actually result in greatest crop profits from the resources and prices specified.

Plans for a 160-Acre Farm Using 1948-52 Prices

Profit-maximizing plans for a 160-acre farm at 1948-52 prices are shown in table 10. With operating capital limited to $1,500, the most profitable rotation is CCOM with no fertilizer. The capital available is sufficient for only 81 acres. Hence, the operator would need to rent out the remainder or farm a smaller unit. He might, of course, plant a large portion of the farm to oats, a low capital crop, to get all his land under cultivation. However, to do so, rather than to plant only 81 acres to CCOM and rent out the remainder, would lower profits.

For $1,500 in capital, the complementary effects of hay in increasing grain yields provides a more economical method of providing fertility than purchasing commercial fertilizer. If funds were invested in fertilizer, with capital at the very low level, fewer acres could be cultivated. Hence, it is more profitable to grow as many acres as is possible with the capital and use no commercial fertilizer. However, as capital increases and allows operation of the entire 160 acres, use of fertilizer becomes feasible and profitable. With $3,000 in operating capital, all 148 acres of cropland can be cultivated, and some fertilizer can be applied. However, the shortage of funds restricts fertilization to 34 acres of CSbCOM. With capital for fertilization, the latter rotation profitably replaces some of the CCOM rotation of the $1,500 capital level. Commercial fertilizer becomes an economical substitute for meadow in attaining high yield levels. It should be noted that 25 percent meadow is the maximum included in any of the plans. The rotations with larger amounts of meadow are not as profitable as those included in table 10.

As the capital level increases, soybeans replace meadow in the rotation until finally a CSb rotation fertilized at the third level maximizes crop profits when capital is unlimiting (S_{8a} in table 10). It should be remembered, of course, that the optimum plans in table 10 are in terms of profit maximization for the crop activities, without consideration of the livestock program on the farm.

The profit-maximizing plan for crops also provides the highest income for the farm as a whole when crops are produced in combinations which give highest returns and the monetary proceeds are, in turn, used to purchase feeds which result in the least-cost animal production. Hence, a farm with unlimiting capital which can purchase hay at the prices used in this study would have greater returns by growing a CSb rotation and purchasing its forage requirements for livestock. However, hogs might still require some meadow rotation for sanitary purposes. Too, many farmers believe that an operation which makes use of farm-raised feeds is less risky than one where some feeds are sold and others are purchased. If meadow is desired in the rotation, the best rotation would be CCOM fertilized at the levels indicated for each capital situation in table 10. For high capital levels, a CCOM rotation fertilized at the highest level

[10] A detailed discussion of the computational procedure for the "simplex" method of linear programming is presented in: Charnes, A., Cooper, W. W. and Henderson, A. An introduction to linear programming. John Wiley and Sons, Inc., New York. 1953.

[11] Profit in this study refers to crop profit. It refers to gross revenue from crops less annual operating expenses. Operating expenses consist of such expenses as tractor fuel, grease, oil, repairs, fertilizer, seed and hired labor.

TABLE 10. GROUP 1 SITUATIONS: OPTIMUM SOLUTIONS AND ALLOCATION OF RESOURCES FOR A 160-ACRE FARM WITH VARIOUS LEVELS OF CAPITAL AND LABOR USING AVERAGE PRICES AND COSTS OF 1948-52.

Situation	Capital level ($)	Labor level*	Most profitable rotations and fertility treatments	Acres of rotations†	Capital requirement ($)	Limitational resources	Monthly labor requirements in hours‡ March (28)	April (187)	May (203)	June (204)	July (241)	Oct. (236)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
S_{1a}	1,500	OL	$CCOM_0$	81	1,500	Capital	7	51	62	65	96	21
S_{2a}	3,000	OL	$CCOM_0$	114	2,110	Land	10	72	87	91	135	29
			$CSbCOM_2$	34	890	Capital	5	25	31	32	41	30
			Total§	148	3,000	....	15	97	118	123	176	59
S_{3a}	4,500	OL	CSb_3	90	2,884	Capital	0	75	135	81	64	148
			$CCOM_2$	58	1,616	Land	9	44	44	54	76	15
			Total§	148	4,500	....	9	119	179	135	140	163
S_{4a}	3,000	OL & FL	(Same solution as S_{2a} since the added labor is not required)									
S_{5a}	4,500	OL & FL	(Same solution as S_{3a} since the added labor is not required)									
S_{6a}	4,600	Unlim.	CSb_3	116	3,691	Capital	0	96	173	103	82	190
			$CCOM_2$	32	909	Land	5	25	25	30	43	8
			Total§	148	4,600	....	5	121	198	133	125	198
S_{7a}	4,700	Unlim.	CSb_3	141	4,497	Capital	0	117	211	126	100	231
			$CCOM_2$	7	203	Land	1	6	5	7	10	2
			Total§	148	4,700	....	1	123	216	133	110	233
S_{8a}	Unlim.**	Unlim.	CSb_3	148	4,750	Land	0	123	220	132	105	243

*OL = operator labor available for field work. FL = family labor consisting of 130 hours for June, July and August. Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

†The estimated total number of acres available for crops on 160-acre farms is 148 acres, thus the total acreage for each plan in this column will never exceed 148 acres.

‡The total number of hours estimated to be available for field work each month after adjusting for inclement weather is indicated in parentheses below each month.

§Total indicates the total quantities of each resource used in the different rotations of an optimum plan.

**Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

would give profits from crop activities only slightly less than for the CSb rotation indicated in table 10. Hence, as indicated later, the CCOM rotation may be preferable for the farmer who has a relatively high capital level and wishes to include livestock in his farm program.

REASONS FOR PLANS

Capital and land are the only limitational resources in the solutions for a 160-acre farm under 1948-52 prices (Group 1 situations in table 10). Capital is the only limitational resource for the $1,500 capital level, while land is the only limitational resource for the situation with unlimiting capital. For situations with capital ranging from $3,000 through $4,700, all of the available capital and land resources are used. Operator labor is not limitational in any plan where it is the only labor resource available (columns 8-13, table 10). While situations S_{7a} and S_{8a} were computed with unlimiting labor, requirements (columns 8-13) show that the operator might handle these plans without hiring help. Only the labor requirements for May and October exceed that of the operator. If necessary, most farmers are willing to spend a few extra hours in the field during these months. Therefore, labor of the operator might well be sufficient for any of the Group 1 plans on a 160-acre farm.

Capital is the resource which limits the plan with $1,500 in capital, since its supply is exhausted before all 148 acres are in cultivation. Why, then, does $CCOM_0$ enter the solution rather than some other rotation? The answer is found by considering resource requirements necessary for $100 crop profit[12] for alternative rotations and fertility levels of C_0, CSb_0 and $CCOM_0$ as shown in table 11. The quantities of capital, land and May labor necessary in fixed proportion for $100 profit of the three alternative rotations are given in columns 5, 6 and 7 of table 11. For example, $100 profit from C_0 requires $55.20 of capital, 3.06 acres of land and 4.71 hours of May labor.

By dividing the available quantity of each resource by the corresponding resource requirement per $100 profit, the total profit permitted by the supply of each resource can be computed for the three rotations. For example, the available amount of capital (column 2) divided by the capital required per $100 profit (column 5) yields total profits permitted by capital for each rotation (column 8). Columns 8, 9 and 10 show the total possible profit permitted by each resource. Since resources for each activity (rotation and fertility level) are used in fixed proportions, production of an activity is terminated whenever the supply of any one (or more) of the available resources is completely exhausted. Thus, for a given rotation, the lowest quantity in column 6, 7 or 8 indicates the highest profit that can be obtained from that rotation. That is, because of a shortage of capital, profits for C_0, CSb_0 and $CCOM_0$ are limited to $2,717, $3,194 and $3,916, respectively. Thus $CCOM_0$ is the most profitable of the 32 activities included in the study for a 160-acre farm under a situation of (1) $1,500 capital, (2) operator labor and (3) 1948-52 prices.

Although $CCOM_0$ is the most profitable rotation with $1,500 in capital, data in table 12 indicate that several rotations and fertility treatments provide only slightly lower crop profits. Rotations of $CSbCOM_2$ and $CSbCOM_0$ provide about $65 and $114 lower profits than $CCOM_0$. Hence, it is likely that many individuals would prefer to include soybeans in the rotation to increase diversification and lessen risks from prices and weather.[13]

Capital limitations frequently cause farmers to adopt a "less than optimum" plan by "spreading their capital." For example, they sometimes raise as much corn as possible and then plant the remainder of the farm to oats, a crop requiring fewer funds per acre. As the figures in table 12 show, rotations such as CSb_0 or continuous oats use more acres and allow more cropland to be planted. However, these rotations provide lower profits than $CCOM_0$. In other words, a farmer with only $1,500 (beyond machinery investment) would be better off to operate only 81 acres and plant it all to a CCOM rotation than to plant the farm to continuous corn or oats to get more acreage in cultivation. This statement applies, of course, only to an owner-operated farm where the operator gets the full return and is on his farm long enough to get the complementary yield effects

[12]Coefficients were converted to requirements per $100 of crop profit by dividing each resource requirement for producing a feed unit of activity by the profit from that feed unit, then multiplying by 100.

[13]For a discussion of diversification see: Heady, Earl O., Kehrberg, Earl W. and Jebe, Emil H. Economic instability and choices involving income and risk in primary or crop production. Iowa Agr. Exp. Sta. Res. Bul. 404. 1954.

TABLE 12. PROFITS AND ACREAGES FOR ALTERNATIVE ROTATIONS WITH $1,500 CAPITAL AND OPERATOR LABOR. AVERAGE 1948-52 PRICES AND COSTS.

Rotation and fertility treatment*	Number of acres†	Profit from crops above fixed costs ($)
$CCOM_0$	81	3,916
$CSbCOM_2$	58	3,851
$CSbCOM_0$	82	3,802
$CCOM_2$	76	3,655
CSb_0	85	3,194
C_0	83	2,717
O_0	116	1,177

*Assume entire acreage allowed by capital is planted to these particular rotations.

†Number of acres allowed by $1,500 in capital.

TABLE 11. QUANTITIES OF RESOURCES REQUIRED FOR $100 PROFIT AND THE TOTAL PROFIT PERMITTED BY EACH RESOURCE FOR THREE ROTATIONS.

Rotation and fertility level	Total available resources			Quantities of each resource required for $100 profit			Total profit permitted by each resource for various rotations*		
	Capital (dollars)	Land (acres)	May labor (hours)	Capital (dollars)	Land (acres)	May labor (hours)	Capital (dollars)	Land (acres)	May labor (hours)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
C_0	1,500	148	203.3	55.20	3.06	4.71	2,717	4,840	4,317
CSb_0	1,500	148	203.3	46.96	2.65	3.97	3,194	5,591	5,123
$CCOM_0$	1,500	148	203.3	38.31	2.06	1.59	3,916	7,181	12,818

*Profit refers to total revenue from crops less annual crop expense, but without fixed costs subtracted.

TABLE 13. QUANTITIES OF RESOURCES REQUIRED FOR \$100 PROFIT AND THE TOTAL PROFIT PERMITTED BY EACH RESOURCE FOR FOUR ROTATIONS.

Rotation and fertility level	Total available resources		Quantities of each resource required for \$100 profit		Total profits permitted by each resource for various rotations*	
	Capital (dollars)	Land (acres)	Capital (dollars)	Land (acres)	Capital (dollars)	Land (acres)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
CSb_3	3,000	148	44.81	1.40	6,695	10,571
$CCOM_0$	3,000	148	38.31	2.06	7,831	7,181
$CCOM_2$	3,000	148	41.04	1.47	7,310	10,068
$CSbCOM_2$	3,000	148	38.95	1.51	7,702	9,801

*Profit refers to total revenue from crops less annual crop expense, but without fixed costs subtracted.

of the hay. The solution may be quite different, however, under a leasing arrangement where the tenant pays all the operating costs but only half the seed and fertilizer costs. Since he pays all "first operating costs" and gets only half the return on unfertilized corn, but pays only half the fertilizer expense and gets half the return, a tenant limited on funds may find it more profitable to grow fewer acres but to fertilize them.[14]

With increase in capital from \$1,500 (S_{1a}) to \$3,000 (S_{2a}) with operator labor, the most profitable solution includes 114 acres of $CCOM_0$ and 34 acres of $CSbCOM_2$ (table 10). The greater capital level permits use of all land and all capital. Only operator labor is in excess (i.e., is not completely used and therefore has no effect on selection of rotations). Data in table 13 illustrate why the plan with \$3,000 differs from the plan with \$1,500. An increase in capital to \$3,000 causes land instead of capital to become the limitational resource for the $CCOM_0$ rotation. A capital level of \$3,000 would permit 148 acres of $CCOM_0$, if the land were all planted to this rotation. However, use of all land for CCOM, rather than the combination shown for \$3,000 in table 10, would lower crop profit by \$612. Capital is in excess for production of $CCOM_0$ alone, and the two rotations (table 10) together are more profitable than $CCOM_0$ alone. A rotation of $CSbCOM_2$ alone provides a profit from crops of only \$90 less than the two rotations in table 10. However, capital is limitational in production of $CSbCOM_2$ alone, because of the higher fertilization level, and the entire 148 acres could not be used. Accordingly, the combination of 114 acres of $CCOM_0$ with 34 acres of $CSbCOM_2$ is most profitable. The linear programming process automatically selects this combination of rotations and fertilization levels as the most efficient in the use of the limiting resources.

As the data in table 10 indicate, $CSbCOM_2$, rather than $CSbCOM_0$ or $CSbCOM_1$, enters the plan for capital levels from \$3,000 through \$4,500. Based on yields, prices and costs used for this group of situations, it is more profitable to go directly to the level 2 fertility treatment than to use a lower fertilization level. This is because crop profit increases faster than costs as fertilizer is added up to level 2. Data in table 14 can be used to compare total crop profit from the various CSbCOM rotations with a capital level of \$3,000. $CSbCOM_2$ provides a profit of nearly \$400 more than $CSbCOM_1$. The $CSbCOM_3$ rotation returns even lower profits for \$3,000 capital. However, with more capital, higher levels of fertilization for rotations with soybeans do maximize profits.

[14]This point is borne out for Clarion-Webster soils dealing with selection of crop rotations and livestock enterprises on a rented farm in a forthcoming publication.

TABLE 14. COMPARISON OF TOTAL CROP PROFITS FOR CSbCOM WITH VARIOUS LEVELS OF FERTILITY WITH RESOURCES OF \$3,000 CAPITAL AND 148 ACRES OF CROPLAND.

Rotation and fertility	Resource requirements per \$100 profit		Number of acres*	Total crop profit above fixed costs (\$)
	Capital (\$)	Land (acres)		
$CSbCOM_0$	39.46	2.16	148	6,852
$CSbCOM_1$	40.97	1.72	126	7,322
$CSbCOM_2$	38.95	1.51	116	7,703
$CSbCOM_3$	47.12	1.54	98	6,366

*Number of acres allowed by \$3,000 capital.

While there is a question of practicability in use of two rotations on the same farm, this practice is not uncommon. A difficulty arises if use of two or more rotations requires several small fields and greater fencing. However, if the new plan provides enough profit, many farmers might wish to divide their farms into different fields and use more than one rotation. Still other farmers might accept a "less-than-optimum" rotation (i.e., such as $CSbCOM_2$) where the optimum combination includes only a small acreage of one rotation and does not cause a large sacrifice in profits.

In going from Situation S_{2a} with \$3,000 to Situation S_{3a} with \$4,500, $CCOM_2$ replaces $CCOM_0$; that is, the same rotation is used but fertilizer is increased from zero to the second level (table 10). Even with a somewhat smaller increment of increase in capital resource, the $CCOM_1$ activity would not have entered the solution. Data in table 15 on yields, costs and returns explain why $CCOM_2$ is more profitable than $CCOM_1$ for the \$4,500 capital level. To obtain yield increases between $CCOM_1$ and $CCOM_2$, the costs involved are those for additional fertilizer and its application and harvesting costs due to increased yields. The "fixed costs" of applying fertilizer are all attained when level 1 is applied. No added "fixed costs" of fertilization are required for level 2, but only the fertilizer. Also, it should be remembered that level 2 does not represent a constant increase in fertilizer over level 1 with nutrients applied in the same ratio as previously on all crops.

TABLE 15. YIELDS, COSTS AND RETURNS FOR CCOM ROTATION AT DIFFERENT FERTILIZATION LEVELS WHEN CAPITAL IS AT \$4,500.

Fertility treatment	CCOM rotations at various fertility levels					
	Feed units per acre	Costs per acre (\$)	Added costs per acre (\$)	Profit per acre (\$)	Added profit per acre (\$)	Average profit per \$1 capital costs (\$)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0	50.09	18.59	......	48.53	....	2.611
1	63.92	25.40	6.81	60.07	11.54	2.364
2	71.76	27.98	2.58	68.48	8.38	2.446
3	72.51	33.82	5.84	63.60	–5.85	1.881

Fertilization is changed in levels and ratios to more nearly meet optimum uses of fertilizer at level 2.[15] Level 2 of fertilizer for corn includes an increase of 30 pounds of available nitrogen over level 1 and no increase in P_2O_5 and K_2O (see table 1): Level 2 includes the same levels and ratios as level 1 for oats and hay. Thus, between fertilizer levels 1 and 2, costs do not increase as rapidly as returns, and level 2 is more profitable under the given capital situation. The relationship of costs to returns is illustrated in column 7, table 15, indicating that $CCOM_2$ gives a higher return per $1 of cost than $CCOM_1$. Hence, $CCOM_1$ never enters the solution when only capital and land are limiting resources. But most important, the added or marginal returns, with capital fixed at $4,500, is $8.38 per acre while added costs are only $2.58 for the prices used.

The data in column 7 of table 15 suggest that when capital is the scarcest resource, $CCOM_0$ will be the first and only activity to enter the solution. A farmer on 160 acres who is an owner-operator on his farm long enough to fully realize complementary effects of hay in the rotation would get greater returns by planting as many acres to CCOM without fertilizer as his funds would permit. As more capital becomes available, he should, to maximize profit, start investing in fertilizer.

Situation S_{6a} has a capital level of $4,600, or $100 more than Situation S_{3a}. As capital is increased towards a non-limitational amount, the rotation with the greatest profit per acre, rather than the one with the greatest profit per dollar when capital is the main limiting resource, enters the solution. A rotation of CSb_3 gives the greatest return per acre. Hence, an increase in capital to $4,700 (Situation S_{7a}) results in a still greater shift to more of the CSb_3 rotation. The increase in crop profit from S_{3a} to S_{6a} is $78.09; whereas, an additional $100 of available capital in Situation S_{7a} increases crop profit by only $67.41. Labor required for the plan with $4,600 capital does not exceed the supply of operator labor. However, with capital at $4,700 ($S_{7a}$), requirements for May labor exceed available operator labor by only 13 hours. From a practical standpoint, however, labor of the operator would be sufficient for the plan of S_{7a}; the operator could work slightly longer days. Also, from a practical standpoint, two rotations (141 acres of CSb_3 and only 7 acres of $CCOM_2$) probably would not be used simultaneously in Situation S_{7a}. A farmer would shift entirely to a CSb_3 rotation, if he were to approach this plan.

When capital becomes non-limitational in Situation S_{8a}, CSb_3 becomes the most profitable plan since this rotation and fertility treatment returns the greatest profit per acre with unlimiting quantities of capital and labor. Neither of these resources limits the plan, and the task is to select the program which gives the greatest return per unit of land. Where capital is limited, the plan returning the most per dollar of capital is most profitable.

A comparison of returns for the rotations with capital and labor unlimiting show that C_3 is only about $230 less profitable than CSb_3. A slight change in either the yields or prices of corn or soybeans would result in a shift between either of these plans. For example, C_3 alone would represent the optimum plan under the following conditions: (1) a price of $1.49 or above for corn, instead of the $1.45 used in the solutions, (2) a price for soybeans of $2.43 or below as compared to the $2.54 used in the solutions, (3) a yield of 81.2 bushels or above for corn, rather than the 80 bushels used, or (4) a decrease in yield in soybeans from 30 bushels per acre to 28.5 and below. With only a slight difference in yields or prices causing C_3 to enter the optimum plan instead of CSb_3, farmers might be indifferent between these two rotations. While the profit from the C_3 rotation compares most closely with that from CSb_3, certain other rotations are only slightly lower in crop profits. For example, a rotation of $CCOM_2$ is only $426 less profitable than CSb_3, while a rotation of $CSbCOM_2$ returns only $718 less than CSb_3. With only small variations in expected prices or yields, any one of the four rotations above would have entered the solution. Hence, even under the yield differentials used in this study, farmers may have quite a range of choice in rotations which yield about the same general level of returns. Rotations examined above include from zero to 25 percent meadow. However, rotations with more meadow cause considerably greater sacrifices in profits.

ADVANTAGE OF CCOM

The results outlined above apply mainly to a farm (1) selling its crops for cash or (2) organizing the most profitable crop plan, and then organizing the most profitable livestock plan separately (with feed being bought or used from the "otherwise sale quantity"). In any case where the livestock plan is integrated with the crop plan and forage consuming livestock can add 26 percent to the value of forage, the $CCOM_2$ rotation would give a greater profit than CSb_3 under unlimiting capital. Also, if the yields of this study should overestimate the long-run possibilities for a continuous CSb_3 rotation by about 4 percent, $CCOM_2$ would be most profitable even if all crops were sold for cash. While it is estimated that high level fertilization of a CSb plan might provide as much organic matter as a $CCOM_2$ rotation and maintain about the same soil structure, later findings might indicate some differences for lower strata of the soil which would be penetrated by the meadow crop of a $CCOM_2$ rotation.

Considering that even on a cash grain basis, CSb_3 under unlimiting funds returns only about $400 more than $CCOM_2$, the latter appears to be the rotational scheme best adapted for the soil situation studied. There is one additional reason why this is true. While cost computations have been on the basis of farmers having their own equipment, some owners would wish to hire someone to combine their oats, rather than to own a combine. Under a CSb_3 rotation, farmers might desire to own both a combine and a corn picker. When depreciated costs are considered for owning both machines on a single farm, as compared to owning only a corn picker, the difference in net crop profits becomes only slightly more than $100. Hence, in terms of (1) similarity of returns, (2) a somewhat greater machinery investment, (3) the possibility of organizing an even higher profit livestock plan and (4) the possibility of some relative errors in long-term yield estimates, the

[15] If level 2 represented an increase of the same ratios on the same crops to equal the increment of level 1, diminishing returns in the conventional sense would be encountered and level 1 would give a greater return per $1 invested than level 2.

$CCOM_2$ rotation would appear preferable for recommendations where the owner has ample capital and labor and will be on the farm long enough to realize the full complementary effects of forages. However, even for a farmer in this situation, rotations including a considerably greater percentage of hay (such as CCOMM, COM and COMM) are not close in profitability under unlimiting capital and labor.

The situation is quite different for a tenant who will not be on the farm for a full rotation cycle and will not gain the complementary effects of hay. If he farms under the tenure situation mentioned and has ample capital and labor, time considerations will cause a rotation such as CSb_3 to have even greater profit advantages over $CCOM_2$ than suggested by the data of table 10.

EFFECT OF A 15-PERCENT DECREASE IN YIELDS ON OPTIMUM PLAN OF S_{2a}

Estimated yields used in this study assume efficient operators who use all auxiliary crop husbandry practices necessary to get per-acre production at indicated levels. Farmers who do not use these added crop husbandry practices might get considerably lower yields (and the greatest number of farmers do get lower yields). Hence, if yields were decreased by (say) 15 percent, what would happen to the optimum plan with $3,000 capital, 148 acres of land and operator labor?

In other words, what is the optimum solution for Situation S_{2a} if we suppose less efficient management than previously assumed and consider lower yields. Using yields which are 15 percent lower than for the solution previously explained results in an optimum plan of 104 acres of $CCOM_0$ and 44 acres of $CSbCOM_2$ with a crop profit of $6,386. This compares to 114 acres of $CCOM_0$ and 34 acres of $CSbCOM_2$ with a $7,793 crop profit in Situation S_{2a}. The decreased yields result in the same rotations with only slightly different acreages. Since all yields are reduced by 15 percent, all land coefficients (1 acre of land divided by yield in feed units) maintain the same relative relationships as in Situation S_{2a}. However, the absolute changes differ, with the greatest reduction for the rotation and fertility levels having the highest yields. Capital costs are changed for each rotation and fertility level since harvesting costs per acre are reduced because of (1) lower yields and (2) different absolute yield changes. Thus, with capital costs relatively lower for $CSbCOM_2$, slightly more $CSbCOM_2$ and slightly less $CCOM_0$ is used when yields are considered to be 15 percent lower than those used previously (S_{2a}).

PLANS FOR A 160-ACRE FARM WITH INCREASES IN FERTILIZER COSTS

The question is often raised whether farmers should "produce their own nitrogen in a meadow rotation," rather than buy it in commercial form if fertilizer costs were to increase relative to crop prices. This section includes plans for situations (S_{9a} through S_{16b} in table 2) where all prices are at 1948-52 levels but fertilizer prices have been raised by 50 percent. The 50-percent increase corresponds to the most recent period when fertilizer prices were highest relative to crop prices (namely, 1941-42).

Comparison of results of tables 10 and 16 shows that the increased fertilizer cost does not change the general types of rotations and fertility combinations used. Only rotations and fertility treatments of $CCOM_0$, $CCOM_2$, $CSbCOM_2$ and CSb_3 enter the optimum plans of situations S_{9a} through S_{14a}; rotations with more meadow are not included in any plan even though fertilizer prices have been increased 50 percent relative to crop prices. These identical activities entered the solutions in situations of Group 1 (table 10). However, there is a considerable difference in acreages of specific rotations at similar resource levels for the two groups of situations.

With the same capital, land and labor, plans for situations S_{9a} through S_{14a} contain rotations with more meadow and less commercial fertilizer than the parallel capital levels in situations S_{1a} to S_{9a} in Group 1. The relatively high price for fertilizer causes some nitrogen

TABLE 16. GROUP 2 SITUATIONS: OPTIMUM SOLUTIONS AND ALLOCATION OF RESOURCES FOR A 160-ACRE FARM WITH VARIOUS LEVELS OF CAPITAL AND LABOR WITH A 50-PERCENT INCREASE IN FERTILIZER COSTS OVER 1948-52. (OTHER PRICES AND COSTS AN AVERAGE OF 1948-52).

Situation (1)	Capital level ($) (2)	Labor level* (3)	Most profitable rotations and fertility treatments (4)	Acres of rotations† (5)	Limitational resources (6)	Capital requirements ($) (7)	Monthly labor requirements in hours‡ March (28) (8)	April (187) (9)	May (203) (10)	June (204) (11)	July (241) (12)	Oct. (236) (13)
S_{9a}	1,500	OL	$CCOM_0$	81	Capital	1,500	7	51	62	65	96	21
S_{10a}	3,000	OL	$CCOM_0$	124	Capital	2,310	3	17	22	22	28	20
			$CSbCOM_2$	24	Land	690	11	79	96	100	148	32
			Total§	148	....	3,000	14	96	118	122	176	52
S_{11a}	4,500	OL	$CCOM_2$	67	Capital	2,144	11	51	52	63	88	17
			$CSbCOM_2$	81	Land	2,356	10	59	74	75	96	70
			Total§	148	....	4,500	21	110	126	138	184	87
S_{12a}	3,000	OL & FL	(Same solution as S_{10a} since the added labor is not required)									
S_{13a}	4,500	OL & FL	(Same solution as S_{11a} since the added labor is not required)									
S_{14a}	Unlim.**	Unlim.	CSb_3	148	Land	5,679	0	123	222	132	105	243

*OL = operator labor available for field work. FL = family labor consisting of 130 hours for June, July and August. Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

†The estimated total number of acres available for crops on 160-acre farms is 148 acres, thus the total acreage for each plan in this column will never exceed 148 acres.

‡The total number of hours estimated to be available for field work each month after adjusting for inclement weather is indicated in parentheses below each month.

§Total indicates the total quantities of each resource in the different rotations of an optimum plan.

**Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

in a longer meadow rotation (i.e., up to 25 percent meadow) to be less costly than inorganic fertilizer for these capital situations. However, the optimum solution does not change under the limited capital situation of S_{9a} and the unlimiting capital and labor situation of S_{14a}. The solution for Situation S_{9a} is the same as for S_{1a} since no fertilizer is used in either plan. Capital is too limited to allow an alternative in plans.

The solution for Situation S_{14a} results in 148 acres of CSb_3, as did S_{8a}. The plan does not change with the higher fertilizer price because capital does not limit the program and because the marginal cost of fertilizer is less than the marginal return even under the increased cost. Under other situations, except S_{9a}, where capital is limited, the return per dollar invested is maintained at a higher level by shifting more toward a CCOM rotation as fertilizer prices are increased by 50 percent. Of course, crop profits for all solutions for situations of Group 2 which use fertilizer at the higher price are lower than corresponding situations of Group 1 where fertilizer is priced at 1948-52 levels. The depression of profits results largely from the higher fertilizer prices used but also from the change in rotational scheme.

Capital and/or land are the limiting resources in the results for all situations of Group 2 presented in table 16. Operator labor is in excess for all situations, except for the months of May and October in Situation S_{14a}. The CSb_3 rotation requires large amounts of labor during May for seedbed preparation, planting and cultivating for both corn and soybeans. Harvesting requirements are high for both crops during October, as compared to a rotation which includes oats and meadow.

Plans for a 160-acre Farm With An Increase in Hay Price

Solutions for situations S_{15a} through S_{20a} (Group 3) were computed with the hay price increased by 36 percent relative to the average 1948-52 price. As mentioned earlier, this adjustment has been used to determine whether, under any realized price ratios of the past, rotations with more hay would have any particular advantage over those with less hay and more fertilizer. The hay prices used are based on the highest hay/corn price ratio of the past; namely, 1920-24. The results are presented in table 17. When compared to parallel resource situations in previous tables, the increase in the price of hay relative to other crops causes a shift to a greater percentage of meadow in the rotations. At the \$1,500 and \$3,000 capital levels of situations S_{15a} and S_{16a}, respectively, $COMM_1$ is the most profitable activity; rotations with soybeans and a smaller proportion of meadow no longer come into the solutions as they did for the lower hay prices in table 10. As capital is increased to \$4,500 in Situation S_{17a} and to unlimiting quantities in Situation S_{20a}, $CCOM_2$ replaces $COMM_1$ and CSb_3 as the optimum rotation and fertility combination.

The plans presented in table 17 are for extremely high hay prices (i.e., \$29.23 per ton). While relatively high prices do occur in years of drouth, there appears to be no aspects of demand in prospect which would cause such a high price of hay, relative to grain, to be realized over a period of years. Hence, the plans of table 17 may have little relevance in the near future except for this conclusion: Future hay prices are not likely to cause rotations with more than 25 percent meadow to be a profitable opportunity for the soil situation and profit-maximizing conditions studied.

Plans Where Labor is Limited by Livestock Requirements

The preceding situations assumed that the labor requirement for livestock owned by farmers did not interfere with field work. That is, livestock would be cared for outside of the 10-hour day allotted for field work or in periods of weather not suited to crop work. Solutions to situations (Group 4) are now considered for a 160-acre farm which has only 260 hours of labor per month for both crops and livestock. This time allotment is adjusted for weather and the average number of cattle, hogs and poultry on farms in north-central Iowa. The labor available in each month for crops on a 160-acre farm is shown in row 5 of table 5.

As table 18 shows, a reduction in labor available for crop production has a marked effect on rotations included in the optimum plans. A rotation of $CCOM_0$

TABLE 17. GROUP 3 SITUATIONS: OPTIMUM SOLUTIONS AND ALLOCATION OF RESOURCES FOR A 160-ACRE FARM USING VARIOUS LEVELS OF CAPITAL AND LABOR WITH HAY PRICE INCREASED BY 36 PERCENT OVER 1948-52 CORRESPONDING TO HIGHEST HAY-GRAIN PRICE RATIO DURING THE PAST 35 YEARS, I.E., 1920-24 (ALL OTHER PRICES AND COSTS ARE AVERAGE OF 1948-52).

Situation (1)	Capital level (\$) (2)	Labor level* (3)	Most profitable rotations and fertility treatments (4)	Acres of rotations† (5)	Capital requirements (\$) (6)	Limitational resources (7)	Monthly labor requirement in hours‡ March (28) (8)	April (187) (9)	May (203) (10)	June (204) (11)	July (241) (12)	Oct. (236) (13)
S_{15a}	1,500	OL	$COMM_1$	69	1,500	Capital	11	34	27	74	103	18
S_{16a}	3,000	OL	$COMM_1$	138	3,000	Capital	22	68	54	148	206	36
S_{17a}	4,500	OL	$CCOM_2$	148	4,142	Land	24	113	114	139	196	38
S_{18a}	3,000	OL & FL	(Same solution as S_{16a} since the added labor is not required)									
S_{19a}	4,500	OL & FL	(Same solution as S_{17a} since the added labor is not required)									
S_{20a}	Unlim.§	Unlim.	$CCOM_2$	148	4,142	Land	24	113	114	139	196	38

*OL = operator labor available for field work. FL = family labor consisting of 130 hours for June, July and August. Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.
†The estimated total number of acres available for crops on 160-acre farms is 148 acres, thus the total acreage for each plan in this column will never exceed 148 acres.
‡The total number of hours estimated to be available for field work each month after adjusting for inclement weather is indicated in parentheses below each month.
§Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

TABLE 18. GROUP 4 SITUATIONS: OPTIMUM SOLUTIONS AND ALLOCATION OF RESOURCES FOR A 160-ACRE FARM WITH VARIOUS CAPITAL AND LABOR RESOURCES WHEN LABOR IS ADJUSTED FOR THE AVERAGE NUMBER OF LIVESTOCK ON 160-ACRE FARMS IN NORTH- CENTRAL IOWA (PRICES AND COSTS ARE AVERAGE OF 1948-52).*

Situation (1)	Capital level ($) (2)	Labor level† (3)	Most profitable rotations and fertility treatments (4)	Acres of rotations‡ (5)	Capital require-ment ($) (6)	Limita-tional resources (7)	Monthly labor requirements in hours§ March (28) (8)	April (109) (9)	May (98) (10)	June (129) (11)	July (140) (12)	Oct. (116) (13)
S_{21a}	1,500	OL	$CCOM_0$	81	1,500	Capital	7	51	62	65	96	21
S_{22a}	3,000	OL	$CCOM_2$	32	902	Capital	5	26	25	30	43	8
			$COMM_1$	0.3	7	May	......	......	......	......	1	......
			$CSbCOM_2$	81	2,091	July	11	59	73	75	96	70
			Total**	113.3	3,000	....	16	85	98	105	140	78
S_{23a}	4,500	OL	CSb_3	16	504	May	0	13	23	14	11	26
			$CCOM_2$	97	2,716	July	16	74	75	91	129	25
			Total**	113	3,220	....	16	87	98	105	140	51
S_{24a}	3,000	OL & FL	$CCOM_0$	87	1,626	Capital	8	56	67	70	104	23
			$COMM_1$	46	990	Land	8	22	18	49	68	12
			$CSbCOM_2$	15	384	May	2	11	13	14	18	13
			Total**	148	3,000	....	18	89	98	133	190	48
S_{25a}	4,500	OL & FL	$CCOM_2$	87	2,442	Land	14	66	67	82	115	23
			COM_2	61	1,543	May	13	40	31	57	92	21
			Total**	148	3,985	....	27	106	98	139	207	44
S_{26a}	Unlim.††	Unlim.	CSb_3	148	4,950	Land	0	123	222	132	105	243

*Average number of livestock on 160-acre farms in north-central Iowa is based on data from surveys of 1950 and 1951.
†OL = operator labor available for field work. FL = family labor consisting of 130 hours for June, July and August. Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.
‡The estimated total number of acres available for crops on 160-acre farms is 148 acres, thus the total acreage for each plan in this column will never exceed 148 acres.
§The total number of hours estimated to be available for field work each month after adjusting for inclement weather is indicated in parentheses below each month.
**Total indicates the total quantities of each resource used in the different rotations of any optimum plan.
††Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

alone is still produced with capital limited to $1,500 while CSb_3 alone is still produced with unlimiting capital and labor levels. However, for situations between these capital levels, the outcomes differ considerably from the parallel situations in Group 1 (table 10). The difference arises because of the limited supply of labor during May and/or July for the situations now under examination.

With both capital and operator labor in May and July limiting production in S_{22a} with $3,000 capital, the optimum plan includes rotations of 32 acres of $CCOM_2$, 0.3 acre of $COMM_1$ and 81 acres of $CSbCOM_2$. (Obviously, however, a farmer would not bother planting a fractional acre of the $CCOM_1$ rotation. $CCOM_1$ enters this solution mainly because of its low May labor requirement per $100 profit.) Adding family labor in June, July and August for Situation S_{24a} results in capital, land and May labor becoming limitational resources (table 18). The most efficient use of this combination of limiting resources results in 87 acres of $CCOM_0$, 46 acres of $COMM_1$ and 15 acres of $CSbCOM_2$. The new plan (S_{24a}) requires family labor above the labor of the operator of only 3 hours for June and 50 hours for July. Crop profit is increased over Situation S_{4a} in table 10 by about $128 from the addition of 53 hours of family labor. The return on the labor is over $2.40 per hour; hence, in the absence of family labor, it might be hired profitably. Or, unless leisure is worth more than $2.40 per hour, the operator could work these extra hours in the absence of family or hired labor.

The solution for Situation S_{24a} is an example illustrating how use of one resource, the extra labor, may cause a reduction in the amount used of a practice such as fertilization; land and capital resources remaining the same. In Situation S_{24a} (table 18), 15 acres of CSbCOM are fertilized at level 2, 46 acres of COMM at level 1, and 87 acres of corn receive no fertilizer. In Situation S_{22a} with less labor, 32 acres of CCOM are fertilized at level 2 and 81 acres of CSbCOM at level 2. Approximately $784 is spent on fertilizer in Situation S_{22a} and only $302 is required in Situation S_{24a}. With the shortage of May and July labor limiting the acreage for rotation crops to 113 acres in Situation S_{22a}, more intensive use of land is made possible on the fewer acres; surplus capital (i.e., that which cannot be used for more acres because of labor limitations) can now be diverted to invest in more fertilizer on fewer acres.[16]

Addition of family labor in Situation S_{25a}, as compared to Situation S_{23a} with only operator labor, results in an optimum plan with 87 acres of $CCOM_2$ and 61 acres of COM_2. Land and May labor are the limitational resources. COM_2 replaces CSb_3 of Situation S_{23a} mainly because of the low May labor requirement per $100 profit. $CCOM_2$ remains in the solution because it is relatively efficient in the use of both May labor and land in producing $100 profit. The plan for Situation S_{25a} requires only 10 hours of family labor in June and only 67 hours in July, beyond labor of the operator. This change results in a return of about $23 for each hour of family labor used. Use of family labor to utilize all land is more profitable than renting out land in the plan for Situation S_{25a}. (This was not the case in Situation S_{24a} where the capital level is $3,000 rather than $4,500.) Again, the operator would be likely to work longer hours to realize this high mar-

[16]An alternative to following this plan would be to grow a "low capital" and "low labor" crop such as oats to get all land cultivated with given resources. However, this procedure would result in less profit than the plan explained in the text. Still, many farmers would follow this procedure rather than to rent out part of their land (see previous discussion in the text).

ginal return from labor if family help were not available. Or he would likely hire labor if it were available and time were absolutely limited for himself or other family members. Situation S_{25a} in table 18, which is limited by labor and includes COM_2, returns \$1,321 less crop profit than Situation S_{3a} in table 10 which also has \$4,500 capital but is not limited in labor.

Results with Hay Value Equal to 50-50 Shares

The hay prices used in the main solutions of table 10 were market averages for baled hay. This price is relatively high for the average quality of all hay produced on north-central Iowa farms. Only better qualities of hay normally move into commercial channels. Hence, since not all hay could be sold at this price, this question arises: How would a lower return for hay affect the optimum plan? A method of "selling hay" for many farmers with a surplus is to rent it out on a 50-50 basis; the owner getting half the hay for use or sale. Hence, an alternative pricing scheme for hay used in this study is to give it half the value assigned previously (i.e., an arrangement equivalent to renting out hay ground on a 50-50 basis). Also, some farm operators desire not to handle haying operations, even though they have ample equipment. The reasons include (1) preference for other types of work, (2) interference with family vacation plans and (3) shortages of operating capital.

Table 19 summarizes the solutions which have been computed under Group 5 with meadow rented out on a 50-50 share basis. The results shown in table 19 are quite similar to those of Group 1 (table 10). A rotation of $CCOM_0$ is most profitable with \$1,500 capital; the rotation gradually shifts to $CCOM_2$ and $CSbCOM_2$ as operating capital is increased. Finally, a CSb_3 rotation alone becomes optimum with unlimiting capital and labor resources. Rotations with a greater percentage of row crops come into the plan at lower capital levels for Group 5 situations than for Group 1. The main reason is that renting out of meadow on 50-50 shares has the same effect as reducing the gross price for hay by 50 percent, thus making row crops relatively more profitable since costs are not reduced proportionately by this practice. In summary, plans for situations with low hay returns do not cause any important shifts away from the rotational plans presented in table 10 where hay and grain prices are both at 1948-52 levels.

Comparison of Plans With Similar Capital Levels

Interpretation on previous pages has emphasized differences of farm plans under different assumptions of capital, labor, price and sharing arrangements for hay. The remainder of this section for 160-acre farms will emphasize differences in plans when the capital is identical but differences exist only in labor, price or sharing arrangements. Only a few of the more salient points will be reviewed and summarized since added interpretations are possible from the tables of previous pages.

\$1,500 capital

The very limited capital situations (i.e., \$1,500) of the five groups discussed previously provide similar plans. Situation S_{15a} (table 17) of Group 3 is the only plan differing significantly from all other \$1,500 situations. This difference is due to the 36-percent increase in hay price for Situation S_{15a} over the other situations with \$1,500 of capital. Situation S_{15a} is the only plan using fertilizer. In all other \$1,500 situations, hay is grown only because of its complementary effect (and not for the value of the hay). The meadow is a more profitable source of nitrogen than commercial fertilizer when capital is extremely short. However, under situations where capital is available for cultivation of the full acreage, commercial fertilizer is a more profitable source of nitrogen.

Each of the situations with \$1,500 of capital results in only about half of the farm being used for crops. The other land would, of course, be rented out if the optimum plan were used. In other words, a farmer should farm 80 acres if he is to maximize profits, rather than to farm 160 acres and plant part of it to a low-capital crop such as oats just to get all land in cultivation.

TABLE 19. GROUP 5 SITUATIONS: OPTIMUM SOLUTIONS AND ALLOCATION OF RESOURCES FOR A 160-ACRE FARM WITH HAY VALUE EQUAL TO 50-50 SHARE BASIS WITH VARIOUS CAPITAL AND LABOR LEVELS (PRICES AND COSTS ARE AVERAGE FOR 1948-52).

Situation (1)	Capital level (\$) (2)	Labor level* (3)	Most profitable rotations and fertility treatments (4)	Acres of rotations† (5)	Capital requirements (\$) (6)	Limitational resources (7)	Monthly labor requirements in hours‡ March (28) (8)	April (187) (9)	May (203) (10)	June (204) (11)	July (241) (12)	Oct. (236) (13)
S_{27a}	1,500	OL	$CCOM_0$	87	1,500	Capital	8	55	67	39	57	22
S_{28a}	3,000	OL	$CCOM_0$	88	1,514	Land	8	56	67	40	58	23
			$CSbCOM_2$	60	1,486	Capital	8	44	55	33	40	52
				Total§ 148	3,000	....	16	100	122	73	98	75
S_{29a}	4,500	OL	CSb_3	117	3,732	Capital	0	97	174	104	83	192
			$CSbCOM_2$	30	752	Land	4	22	28	16	20	26
			$CCOM_2$	1	16	May	1	1	1	1	1	1
				Total§ 148	4,500	....	5	120	203	121	104	219
S_{30a}	3,000	OL & FL		(Same solution as Situation S_{28a})								
S_{31a}	4,500	OL & FL		(Same solution as Situation S_{29a})								
S_{32a}	Unlim.**	Unlim.	CSb_3	148	4,750	Land	0	123	222	132	105	243

*OL = operator labor available for field work. FL = family labor consisting of 130 hours for June, July and August. Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.
†The estimated total number of acres available for crops on 160-acre farms is 148 acres, thus the total acreage for each plan in this column will never exceed 148 acres.
‡The total number of hours estimated to be available for field work each month after adjusting for inclement weather is indicated in parentheses below each month.
§Total indicates the total quantities of each resource used in the different rotations of an optimum plan.
**Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

$3,000 CAPITAL

Comparison of plans for all situations using $3,000 of capital and operator labor indicates that only four rotations, in various amounts and combinations, occur in these plans. A $COMM_1$ rotation enters Situation S_{16a} because of the high hay price (table 17). Only rotations of $CCOM_0$, $CCOM_2$ and $CSbCOM_2$ enter the other solutions (tables 10, 16, 18 and 19). CCOM and CSbCOM are rotations commonly found in the area being considered. Comparison of solutions for situations S_{2a} (table 10) and S_{10a} (table 16) shows that the high fertilizer price in the latter case results in the use of more $CCOM_0$ and less $CSbCOM_2$; less commercial fertilizer and a greater proportion of meadow is used because of the higher price of fertilizer. The plan for Situation S_{28a} (table 19) has a greater acreage of $CSbCOM_2$ and less of $CCOM_0$ than either situation S_{2a} or S_{10a} (tables 10 and 16). The difference is due to the reduced gross price for hay where hay is valued on the basis of 50-50 shares under S_{28a}. In the $3,000 situation where labor is adjusted for the average number of livestock in Situation S_{22a} (table 18), the shortage of operator labor results in a heavier application of fertilizer on CCOM than in the other situations.

$4,500 CAPITAL

For plans with $4,500 of capital, there is only $150 difference between crop profits for Situation S_{29a} where hay land is rented out (table 18) and Situation S_{3a} (table 10). The lower price for meadow in S_{29a} does not have as much effect on profit as under the $3,000 capital levels, since the plan for S_{29a} includes only 6 acres of meadow. Thus, at the $4,500 capital level, renting out the hay ground on shares and spending the capital released from haying operations on rotations containing more row crops and more fertilizer is almost as profitable as where the operator harvests the entire crop and sells it at 1948-52 prices. In other words, as the amount of capital increases, there are more alternative plans open to the farmer; plans which have only slight differences in crop profit.

UNLIMITING CAPITAL

With one exception, a rotation of CSb_3 is the most profitable rotation in all situations with no restrictions on capital and hired labor. The exception is the plan for Situation S_{20a} where hay prices are high relative to grain prices (table 17), and $CCOM_2$ is the most profitable rotation. The use of rather heavily fertilized row crops in the cropping plan with unlimiting capital again raises the question of whether these rotations can be expected to be most profitable over a long period of time.[17] As was pointed out earlier, a recommendation of CCOM under unlimiting capital might well be best considering (1) uncertainties of long-run yields under a CSb rotation, (2) farm ownership, (3) the possibility of increasing forage returns through livestock and (4) lowering machine costs by not owning a combine. Also, at the higher capital level the farmer has several plans which will fit his resource situation. Some of these plans give quite similar returns. Even with a low return for hay under 50-50 share rates (the situation with the maximum difference between meadow and non-meadow rotations), the return is only $1,092 less for $CCOM_2$ than for CSb_3 with unlimiting capital. More than 25 percent meadow lowers crop profits by much more, even where capital is unlimiting. However, as pointed out earlier, the CSb rotation would have particular advantages for the tenant who will not be on his farm long enough to realize the complementary effects of hay in a CCOM rotation.

[17]The difference between $CCOM_2$ and CSb_3 is only $426 for an unlimiting capital situation where hay sells at 1948-52 prices.

RESULTS OF SITUATIONS FOR A 240-ACRE FARM

Preceding sections presented the most profitable plans for various resource and price situations for a 160-acre farm. The following sections deal with the optimum plans for parallel resource situations for a 240-acre farm (see table 2 for resource situations).

SITUATIONS WITH 1948-52 PRICES

The most profitable plans for the very limited and unlimiting capital situations of Group 1 on 240-acre farms (table 20) are similar to those on 160-acre farms (table 10). Rotations of $CCOM_0$ and CSb_3, respectively, for these situations are the most profitable activities for both sizes of farms. However, for resource situations between the extremes of limited and unlimiting capital, optimum plans for a 240-acre farm usually contain more meadow and use less fertilizer than plans for a 160-acre farm. As capital is increased on 240-acre farms with only operator labor, solutions show a gradual shift from $CCOM_0$ to rotations containing more row crops and higher fertility treatments. (A similar "trend" holds true for 160-acre farms.) One difference noted in the solutions on the two sizes of farms is: On 240-acre farms, labor becomes an important factor in selecting optimum plans, especially when more capital becomes available (e.g., situations S_{3b}, S_{6b} and S_{7b} in table 20). With more capital, a shortage of labor tends to result in rotations with less meadow and greater use of commercial fertilizer.

In situations S_{1b} and S_{2b}, with $1,500 and $3,000 of capital, this resource limits acreage to about 81 and 162 acres of $CCOM_0$, respectively (table 20). Since $CCOM_0$ requires the lowest amount of capital per unit of net return, it is the most profitable rotation for both situations. Under the conditions of this study, farmers with about $3,000 operating capital and a 240-acre farm would realize greater crop profits if they rented out part of their land, rather than cultivated the entire farm with part of it planted to a low-capital crop. A more obvious recommendation is this: An operator sufficiently limited on funds would make greater crop profits if he farmed a smaller unit devoted to an optimal rotation and fertilization plan, rather than attempting to operate a larger farm devoted to crops and practices which give low returns.

At an operating capital level of $4,500, nearly all land can be used but capital and July labor limit the plan. The latter two resources determine the most profitable crop combination of 102 acres of $CCOM_0$ and 101 acres of $CSbCOM_2$. With $6,000 of capital and

TABLE 20. GROUP 1 SITUATIONS: OPTIMUM SOLUTIONS AND ALLOCATION OF RESOURCES FOR 240 ACRES OF LAND, VARIOUS LEVELS OF CAPITAL AND LABOR USING AVERAGE PRICES AND COSTS OF 1948-52.

Situation (1)	Capital level ($) (2)	Labor level* (3)	Most profitable rotations and fertility treatments (4)	Acres of rotations† (5)	Capital require-ments ($) (6)	Limita-tional resources (7)	Monthly labor requirements in hours‡ March (28) (8)	April (187) (9)	May (203) (10)	June (204) (11)	July (241) (12)	Oct. (236) (13)
S_{1b}	1,500	OL	$CCOM_0$	81	1,500	Capital	7	51	62	65	96	21
S_{2b}	3,000	OL	$CCOM_0$	162	3,000	Capital	14	102	124	130	192	42
S_{3b}	4,500	OL	$CCOM_0$	102	1,900	Capital	9	65	79	82	121	27
			$CSbCOM_2$	101	2,600	July labor	13	73	91	93	120	87
			Total§	203	4,500	....	22	138	170	175	241	114
S_{4b}	3,000	OL & FL	(Same solution as S_{2b} above since added labor does not alter capital restrictions)									
S_{5b}	4,500	OL & FL	$CCOM_0$	178	3,298	Land	16	113	137	142	211	46
			$CSbCOM_2$	46	1,202	Capital	6	34	42	43	55	40
			Total§	224	4,500	....	22	147	179	185	266	86
S_{6b}	6,000	OL	$CSbCOM_2$	32	818	Capital	4	23	28	29	38	27
			$CCOM_2$	126	3,537	May	20	96	98	118	167	33
			CSb_3	52	1,645	July	6	43	77	46	36	84
			Total§	210	6,000	....	30	162	203	193	241	144
S_{7b}	6,000	OL	$CSbCOM_2$	134	3,461	Capital	17	97	122	124	160	116
			$CCOM_2$	56	1,561	Land	9	42	43	52	74	14
			$COMM_1$	11	244	March	2	6	4	12	17	3
			CSb_3	23	734	May	0	19	34	20	16	38
			Total§	224	6,000	....	28	164	203	208	267	171
S_{8b}	Unlim.**	Unlim.	CSb_3	224	7,375	Land	0	186	336	200	158	367

*OL = operator labor available for field work. FL = family labor consisting of 130 hours for June, July and August. Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

†The estimated total number of acres available for crops on 240-acre farms is 224 acres, thus the total acreage for each plan in this column will never exceed 224 acres.

‡The total number of hours estimated to be available for field work each month after adjusting for inclement weather is indicated in parentheses below each month.

§Total indicates the total quantities of each resource used in the different rotations of an optimum plan.

**Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

operator labor (Situation S_{6b} in table 20) the optimum plan includes 32 acres of $CSbCOM_2$, 126 acres of $CCOM_2$ and 52 acres of CSb_3. These rotations enter the solution since they use the limiting resources of capital, May labor and July labor most efficiently: (1) $CCOM_2$ and $CSbCOM_2$ enter the solution mainly because of their relatively low capital and May and July labor requirements per $100 crop profit. (2) CSb_3 enters the solution because of its low July labor coefficient. While some other rotations have lower resource requirements per $100 profit for individual resources than CSb_3, the latter uses all other resources in combination most effectively. The family labor in Situation S_{7b} results in capital, land, March and May labor being combined most profitably when the plan includes: (1) 134 acres of $CSbCOM_2$, because of its relatively low requirements of resources, (2) 23 acres of CSb_3, because of its low requirements for land and March labor for each $100 profit above fixed costs and (3) 11 acres of $COMM_1$, because of its low May labor requirement. The addition of family labor in S_{7b} increases crop profits by about $550 over S_{6b}, where only operator labor is available. Also, the availability of a larger labor supply results in use of less fertilizer and more meadow in the rotations.

Several situations in table 20 have optimum plans which include three or four rotations. Farmers may not desire to use as many as three rotations, especially when one or more of the rotations consists of only a few acres. However, where one of the several rotations is CSb, use of this rotation presents little difficulty since it consists only of row crops. However, it should not be difficult to arrange for two other rotations on a 240-acre farm. An alternative to the plan shown in table 20 for Situation S_{6b} is a single rotation of $CSbCOM_2$. This rotation is only about $975 less profitable than the plan for S_{6b} and is limited by the scarcity of July labor. Where only operator labor is available, labor is the main limitation to higher profits for most rotations used singly on a 240-acre farm in Situation S_{6b}. Scarcity of March labor would limit a single rotation of $CCOM_2$ to a crop profit of about $2,700 less than for the plan shown in table 20 for Situation S_{6b}. Similarly, scarcity of May labor for the operator would limit use of CSb_3 alone and cause a crop profit of $4,710 less than for the plan shown for S_{6b}. When labor and capital become nonlimitational, single rotations in order of magnitude of crop profits are: (1) CSb_3, (2) C_3, (3) $CCOM_2$ and (4) $CSbCOM_2$.

Results for Other Groups

Plans for situations under other groups (see table 2) have been worked out for 240-acre farms, just as for 160-acre farms. The results are presented in tables 21, 22, 23 and 24. However, the results are not discussed because differences are the same as those explained for all groups of situations for 160-acre farms and for Group 1 situations for 240-acre farms.

TABLE 21. GROUP 2 SITUATIONS: OPTIMUM SOLUTIONS AND ALLOCATION OF RESOURCES WITH 240 ACRES OF LAND, VARIOUS LEVELS OF CAPITAL AND LABOR, WHEN FERTILIZER PRICES ARE INCREASED BY 50 PERCENT TO THE HIGHEST PRICE RELATIVE TO CORN DURING PAST 15 YEARS, I.E., 1941-42 (OTHER PRICES AND COSTS ARE AVERAGE OF 1948-52).

Situation (1)	Capital level ($) (2)	Labor level* (3)	Most profitable rotations and fertility treatments (4)	Acres of rotations† (5)	Capital requirements ($) (6)	Limitational resources (7)	Monthly labor requirements in hours‡: March (28) (8)	April (187) (9)	May (203) (10)	June (204) (11)	July (241) (12)	Oct. (236) (13)
S_{9b}	1,500	OL	$CCOM_0$	81	1,500	Capital	7	51	62	65	96	21
S_{10b}	3,000	OL	$CCOM_0$	162	3,000	Capital	14	102	124	.130	192	42
S_{11b}	4,500	OL	$CSbCOM_0$	177	3,240	Capital	12	111	161	145	192	153
			$CSbCOM_2$	38	1,112	May	5	27	35	35	46	33
			CSb_2	5	148	July	0	4	7	4	4	8
			Total§	220	4,500	....	17	142	203	184	242	194
S_{12b}	3,000	OL & FL	(Same solution as S_{10b} above since added labor does not alter capital restrictions)									
S_{13b}	4,500	OL & FL	$CCOM_0$	192	3,567	Capital	17	122	148	154	228	50
			$CSbCOM_2$	32	933	Land	4	23	29	30	38	28
			Total§	224	4,500	....	21	145	177	184	266	78
S_{14b}	6,000	OL	$CSbCOM_0$	14	261	Capital	1	9	13	12	15	12
			$CSbCOM_2$	178	5,180	Land	23	130	162	165	212	154
			CSb_2	19	559	July	0	16	28	17	14	31
			Total§	211	6,000	....	24	155	203	194	241	197
S_{15b}	6,000	OL & FL	$CCOM_0$	48	902	Capital	4	31	37	39	58	13
			$CSbCOM_2$	176	5,098	Land	23	127	159	162	209	151
			Total§	224	6,000	....	27	158	196	201	267	164
S_{16b}	Unlim.**	Unlim.	CSb_3	224	8,869	Land	0	186	336	200	158	367

*OL = operator labor available for field work. FL = family labor consisting of 130 hours for June, July and August. Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.
†The estimated total number of acres available for crops on 240-acre farms is 224 acres, thus the total acreage for each plan in this column will never exceed 224 acres.
‡The total number of hours estimated to be available for field work each month after adjusting for inclement weather is indicated in parentheses below each month.
§Total indicates the total quantities of each resource used in the different rotations of an optimum plan.
**Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

TABLE 22. GROUP 3 SITUATIONS: OPTIMUM SOLUTIONS AND ALLOCATION OF RESOURCES USING 240 ACRES OF LAND, VARIOUS LEVELS OF CAPITAL AND LABOR, WITH HAY PRICE INCREASED TO THAT OF HIGHEST HAY-CORN RATIO DURING PAST 35-YEAR PERIOD, I.E., 1920-24 (ALL OTHER PRICES AND COSTS ARE AVERAGE OF 1948-52).

Situation (1)	Capital level ($) (2)	Labor level* (3)	Most profitable rotations and fertility treatments (4)	Acres of rotations† (5)	Capital requirements ($) (6)	Limitational resources (7)	Monthly labor requirements in hours‡: March (28) (8)	April (187) (9)	May (203) (10)	June (204) (11)	July (241) (12)	Oct. (236) (13)
S_{17b}	1,500	OL	$COMM_1$	69	1,500	Capital	11	34	21	74	103	18
S_{18b}	3,000	OL	$COMM_1$	138	3,000	Capital	23	68	53	148	206	36
S_{19b}	4,500	OL	$COMM_1$	69	1,488	Capital	11	34	26	73	102	18
			$CSbCOM_2$	117	3,012	July	15	85	106	108	139	101
			Total§	186	4,500	....	26	119	132	181	241	119
S_{20b}	3,000	OL & FL	(Same solution as S_{18b} above since added labor does not alter capital restrictions.)									
S_{21b}	4,500	OL & FL	$COMM_0$	18	321	Capital	2	8	7	16	24	5
			$COMM_1$	116	2,490	Land	18	56	44	122	171	30
			$CCOM_0$	90	1,689	March	8	58	70	73	108	24
			Total§	224	4,500	....	28	122	121	211	303	59
S_{22b}	Unlim.**	Unlim.	$CCOM_2$	224	6,320	Land	37	171	172	210	296	58

*OL = operator labor available for field work. FL = family labor consisting of 130 hours for June, July and August. Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.
†The estimated total number of acres available for crops on 240-acre farms is 224 acres, thus the total acreage for each plan in this column will never exceed 224 acres.
‡The total number of hours estimated to be available for field work each month after adjusting for inclement weather is indicated in parentheses below each month.
§Total indicates the total quantities of each resource used in the different rotations of an optimum plan.
**Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

TABLE 23. GROUP 4 SITUATIONS: OPTIMUM SOLUTIONS AND ALLOCATION OF RESOURCES WITH 240 ACRES OF LAND, VARIOUS LEVELS OF CAPITAL AND LABOR WHEN LABOR FOR AVERAGE NUMBER OF LIVESTOCK ON A 240-ACRE FARM IN NORTH-CENTRAL IOWA IS CONSIDERED.* (ALL OTHER PRICES AND COSTS ARE AVERAGE OF 1948-52.)

Situation (1)	Capital level ($) (2)	Labor level† (3)	Most profitable rotations and fertility treatments (4)	Acres of rotations‡ (5)	Capital require-ments ($) (6)	Limita-tional resources (7)	Monthly labor requirements in hours§: March (28) (8)	April (118) (9)	May (108) (10)	June (139) (11)	July (151) (12)	Oct. (142) (13)
S_{23b}	1,500	OL	$CCOM_0$	81	1,500	Capital	7	51	62	65	96	21
S_{24b}	3,000	OL	$CCOM_0$	32	596	Capital	3	20	25	26	38	8
			$COMM_1$	4	88	May	1	2	2	4	6	1
			$CSbCOM_2$	90	2,316	July	12	65	81	83	107	77
			Total**	126	3,000	....	16	87	108	113	151	86
S_{25b}	4,500	OL	$CCOM_2$	104	2,316	May	17	80	80	98	138	27
			CSb_3	18	579	July	0	15	27	16	13	30
			Total**	122	3,502	....	17	95	107	114	151	57
S_{26b}	3,000	OL & FL	$CCOM_0$	124	2,297	Capital	11	79	95	99	147	32
			$COMM_1$	32	703	May	5	16	12	34	48	8
			Total**	156	3,000	....	16	95	107	133	195	40
S_{27b}	4,500	OL & FL	$COMM_0$	41	719	Capital	3	18	16	36	54	11
			$COMM_1$	110	2,392	March	18	55	42	118	164	28
			$CSbCOM_2$	52	1,339	May	7	38	47	48	62	45
			CSb_3	2	50	July	0	1	2	1	1	3
			Total**	205	4,500	....	28	112	107	203	281	87
S_{28b}	Unlim.††	Unlim.	CSb_3	224	7,669	Land	0	186	336	200	158	369

*Average number of livestock on 240-acre farms in north-central Iowa is based on data from surveys of 1950 and 1951.

†OL = operator labor available for field work. FL = family labor consisting of 130 hours for June, July and August. Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

‡The estimated total number of acres available for crops on 240-acre farms is 224 acres, thus the total acreage for each plan in this column will never exceed 224 acres.

§The total number of hours estimated to be available for field work each month after adjusting for inclement weather is indicated in parentheses below each month.

**Total indicates the total quantities of each resource in the different rotations of an optimum plan.

††Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

TABLE 24. GROUP 5 SITUATIONS: OPTIMUM SOLUTIONS AND ALLOCATION OF RESOURCES USING 240 ACRES OF LAND, VARIOUS LEVELS OF CAPITAL AND LABOR WHEN MEADOW IS RENTED OUT ON 50-50 SHARE BASIS (PRICES AND COSTS ARE AVERAGE OF 1948-52).

Situation (1)	Capital level ($) (2)	Labor level* (3)	Most profitable rotations and fertility treatments (4)	Acres of rotations† (5)	Capital require-ments ($) (6)	Limita-tional resources (7)	Monthly labor requirements in hours‡: March (28) (8)	April (187) (9)	May (203) (10)	June (204) (11)	July (241) (12)	Oct. (236) (13)
S_{29b}	1,500	OL	$CCOM_0$	87	1,500	Capital	8	55	67	39	57	22
S_{30b}	3,000	OL	$CCOM_0$	174	3,000	Capital	15	111	134	78	114	45
S_{31b}	4,500	OL	$CCOM_0$	138	2,388	Capital	12	88	106	62	91	36
			$CSbCOM_2$	86	2,112	Land	11	62	78	46	56	74
			Total§	224	4,500	....	23	150	184	108	147	110
S_{32b}	3,000	OL & FL	(Same solution as S_{30b} above since added labor does not alter capital restrictions.)									
S_{33b}	4,500	OL & FL	(Same solution as S_{31b} above since added labor does not alter capital restrictions.)									
S_{34b}	Unlim.**	Unlim.	CSb_3	224	7,375	Land	0	186	336	200	158	367

*OL = operator labor available for field work. FL = family labor consisting of 130 hours for June, July and August. Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

†The estimated total number of acres available for crops on 240-acre farms is 224 acres, thus the total acreage for each plan in this column will never exceed 224 acres.

‡The total number of hours estimated to be available for field work each month after adjusting for inclement weather is indicated in parentheses below each month.

§Total indicates the total quantities of each resource used in the different rotations of an optimum plan.

**Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

USE OF LINEAR PROGRAMMING FOR MAXIMIZING FEED UNITS

The main objective of preceding sections was to determine cropping and fertilization plans which result in maximum crop profits. However, linear programming specifies the plans which allow maximization of physical quantities. Conservation planners and others are sometimes interested in rotation plans to maximize feed units. Or, during a war or emergency, planners may be interested in the plan which gives maximum feed production from a given collection of resources.

A few solutions have been computed, for the same farm situations used previously, using feed units of rotation as the maximizing criterion. Rotations and fertility levels have been selected to provide a maximum number of feed units under various capital and labor situations on a 160-acre farm. Solutions maximizing feed units have been computed only for the Group 6 situations (table 25). The Group 6 situations parallel the Group 1 situations except that feed units are maximized in the Group 6 situations, while crop profits are maximized in the Group 1 situations. (Feed units of different crops and rotations do not, of course, substitute at a constant rate for one another in producing livestock.)

TABLE 25. OPTIMUM SOLUTIONS AND ALLOCATION OF RESOURCES FOR GROUP 6 SITUATIONS WHERE FEED UNITS OF ROTATION ARE MAXIMIZED USING 160 ACRES OF LAND, VARIOUS LEVELS OF CAPITAL AND LABOR, WITH AVERAGE COSTS OF 1948-52.

Situation (1)	Capital level ($) (2)	Labor level* (3)	Most profitable rotations and fertility treatments (4)	Acres of rotations† (5)	Capital requirements ($) (6)	Limitational resources (7)	Monthly labor requirements in hours‡ March (28) (8)	April (187) (9)	May (203) (10)	June (204) (11)	July (241) (12)	Oct. (246) (13)	Feed units produced (14)
S_{33a}	1,500	OL	$COMM_1$	69	1,500	Capital	11	34	27	74	103	18	4,277
S_{34a}	3,000	OL	$COMM_1$	138	3,000	Capital	23	68	53	147	206	36	8,554
S_{35a}	4,500	OL	$CCOM_2$	128	3,588	Capital	21	98	99	120	170	33	9,202
			C_3	20	912	Land	0	21	30	18	15	20	1,585
			Total§	148	4,500	....	21	119	129	138	185	53	10,787
S_{36a}	3,000	OL & FL	(Same solution as S_{34a} above since added labor does not alter capital restrictions.)										
S_{37a}	4,500	OL & FL	(Same solution as S_{35a} above since added labor does not alter capital restrictions.)										
S_{38a}	Unlim.**	Unlim.	C_3	148	6,869	Land	0	159	228	136	111	153	11,840

*OL = operator labor available for field work. FL = family labor consisting of 130 hours for June, July and August. Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

†The estimated total number of acres available for crops on 160-acre farms is 148 acres, thus the total acreage for each plan in this column will never exceed 148 acres.

‡The total number of hours estimated to be available for field work each month after adjusting for inclement weather is indicated in parentheses below each month.

§Total indicates the total quantities of each resource used in the different rotations of an optimum plan.

**Unlim. = unlimiting, meaning that this resource is available in sufficient quantities so that it does not limit production.

Plans which result in maximization of feed units of rotation for Group 6 situations (see table 2) are shown in table 25. At $1,500 and $3,000 capital levels, the plan includes only a COMM rotation, a higher percentage of hay than at higher capital levels. As capital and labor are increased, greater quantities of corn with heavier fertilization are included. $COMM_1$ enters the solution at lower capital levels because of its greater return of feed units per unit of capital. A rotation of $CCOM_2$ enters where capital is less limiting. Finally, a rotation of continuous corn with heavy fertilization enters the unlimiting capital and labor situation (S_{38a}). Although it gives less feed per $1 of capital, it results in more feed units per unit of land and labor in combination than does a CCOM rotation.

LIMITATIONS OF THE STUDY

The results of this study show the importance of considering different quantities and combinations of resources of land, labor and capital in selecting rotations and fertility treatments for any farm. Similarly, the effects of changes in prices of products and changes in costs of inputs such as fertilizer on the most profitable plans are illustrated. In other words, the proper selection of rotations and fertility treatments, or their combinations, is a complex problem which must consider the complete economic environment of the farm. Recommendations should differ between farms and on the same farm, depending on the resource-price situation.

As is true of all experiments and research procedures, this linear programming analysis is not without its limitations. The coefficients used in computations are estimated to be averages for a period of years. Although various prices, costs and yields were used, each individual solution is computed without adjustments for uncertainty. While a farmer may attain average yields over a period of time, variations between years occur because of weather conditions, disease, insects and other variables exogeneous to the farm. Farmers with adequate capital may well organize their units to attain outcomes for the average yields of a period of years. However, some farmers may wish to take precautions to meet poor yields of individual years. The desire or need for a certain minimum income often results in selecting a "less than optimum rotation and fertility level" in many instances. While linear programming allows examination of plans for meeting uncertainty, this type of analysis is not included in the study.

Another limitation of this study is that only four levels of fertility are included in the analysis. Actually, there are many levels and combinations of fertilizers which farmers can use. However, the results do show which of the four levels or combinations of fertility are most profitable under various situations.

The labor data used in this study relate to monthly requirements and supplies of this resource and suppose that labor from one month cannot substitute for that of another. This degree of "labor rigidity" may be too severe for many farms.

A final limitation of the study deals with yield coefficients. Yields included assume efficient crop husbandry or management. Too, the relative differences in yields used for the various rotations are the best estimates possible from existing experiments. Additional experiments may prove that some of these will need revision at a later time. However, regardless of these limitations, the fundamental principles developed and illustrated in this study have permanent value in recommendations. They indicate how recommendations and decisions on the best rotational and fertilization plans need to differ for farms on the same soil type (or the same farm), depending on the operator's capital and labor supply, the prices of crops and input quantities, the crop-sharing arrangement of the farm, and the size of the farm.